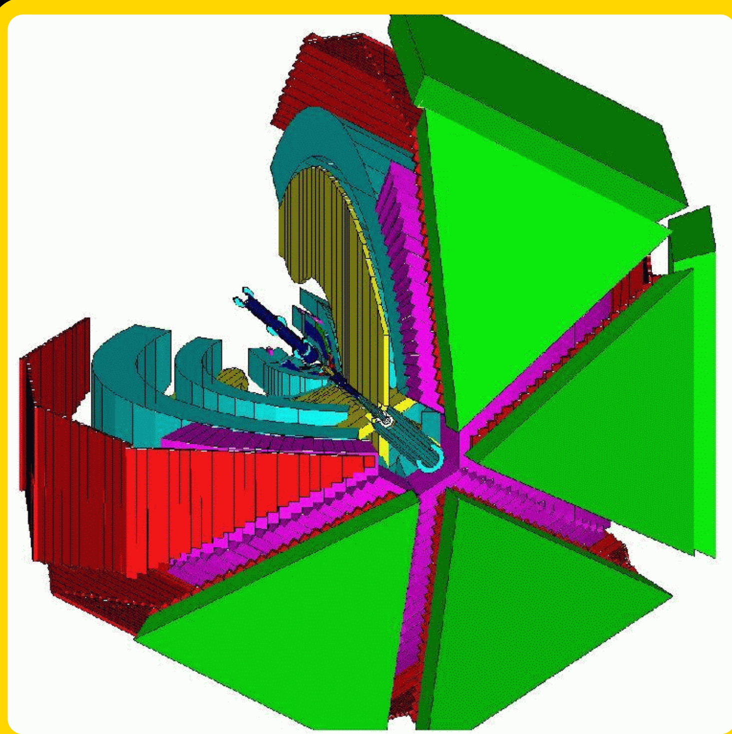
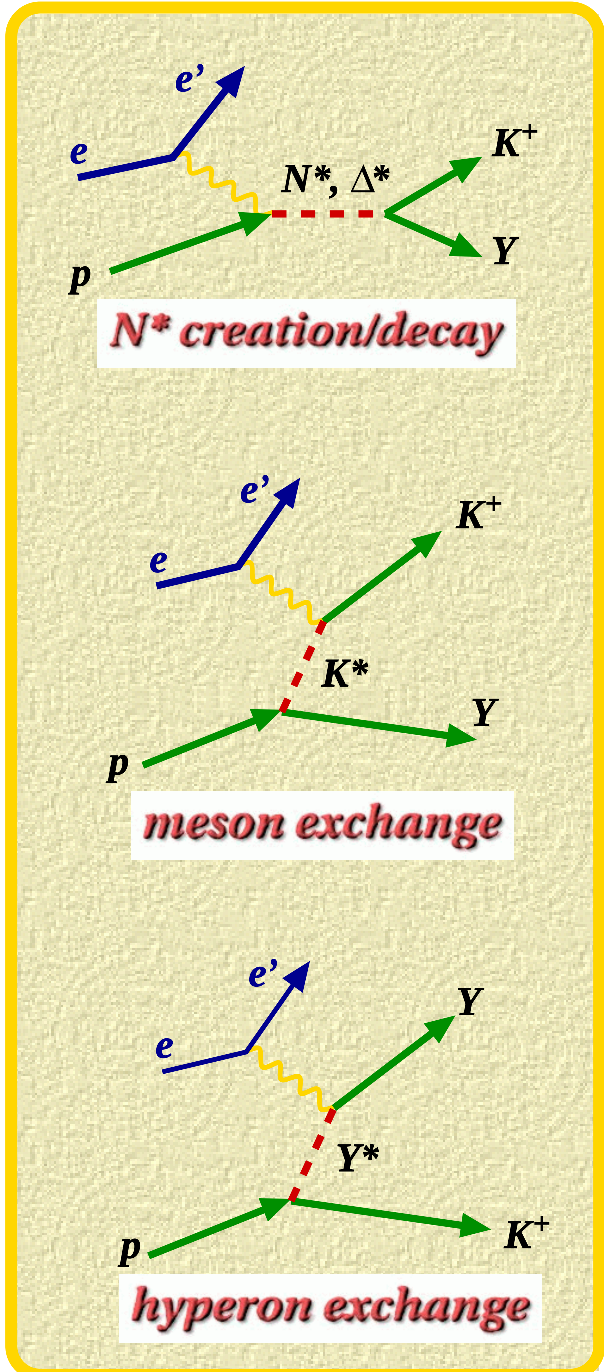
The Strangeness Physics Program at CLAS

Daniel S. Carman
Ohio University

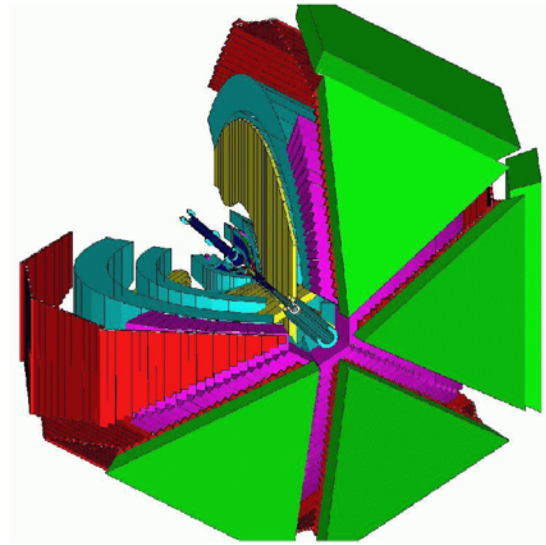


Outline

- **Physics Motivation**
  - *Hadronic structure*
  - *Strangeness physics*
  - *Reaction dynamics*
- **Formalism**
  - *Different observables*
- **Physics Models**
- **Selected Physics Results**
  - *Cross sections & spin observables*
  - *Photoproduction*
  - *Electroproduction*
- **Summary / Conclusions**



N* Physics at CLAS



- **One of the main physics goals of the CLAS program is to probe the structure of the nucleon and its excited states.**

  → ***The N* spectrum is the emblem of QCD just like the hydrogen atom spectrum is the emblem of quantum mechanics.*** ***(F. Lee)***

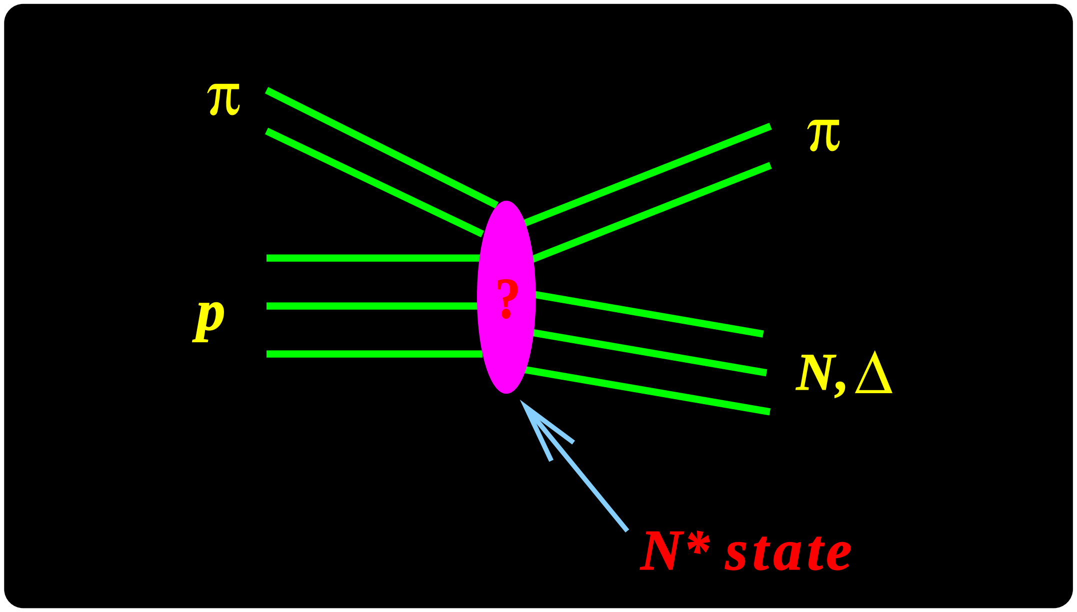
- **Obtain accurate electromagnetic production cross sections and spin observables over a broad kinematic range.**

  → ***Complete coverage of hadronic decay final state.***

- **Determine the appropriate degrees of freedom to describe hadronic matter as a function of the relevant energy/distance scale.**

  → ***Better understand the connections between the different scales.***

Why Strangeness Production?



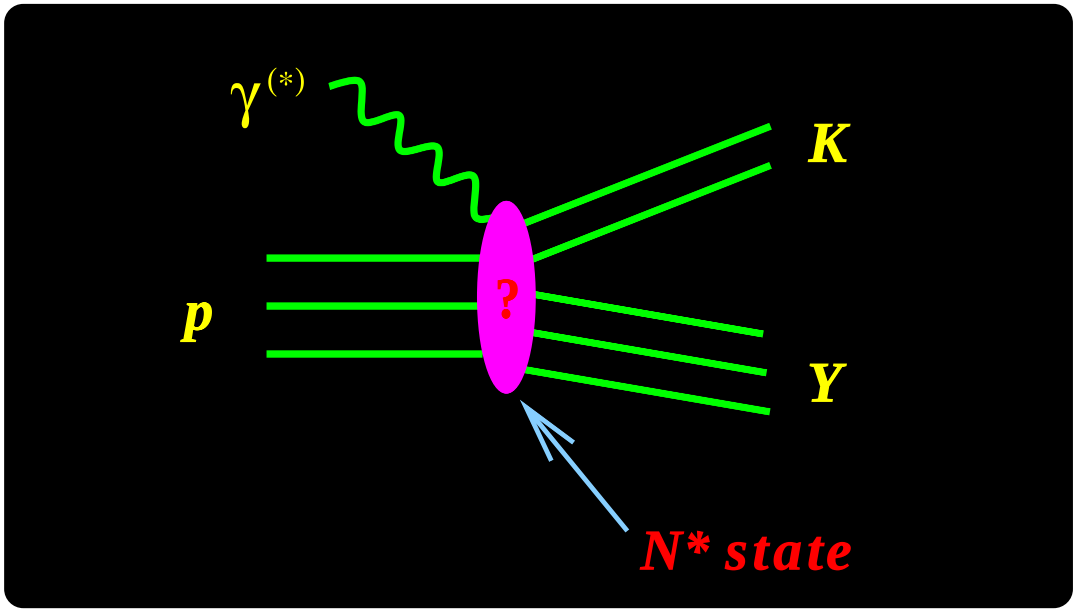
- **Most of what we know about the N* spectrum comes from:**

$$\pi + N \rightarrow (N^* \ \text{or} \ \Delta^*) \rightarrow \pi + N \ \text{or} \ \pi + \Delta$$

- **Processes involving strange particle production are complementary.**

$$\gamma^{(*)} + N \rightarrow (N^* \ \text{or} \ \Delta^*) \rightarrow K + Y$$

Why Strangeness Production?



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$$\gamma^{(*)} + N \rightarrow (N^* \text{ or } \Delta^*) \rightarrow K + Y$$

(different couplings involved)

"Missing" Quark Model Baryons

- **The constituent quark model predicts more states than seen experimentally.**

  → **Perhaps these "missing" states decay into KY channels.**

  – **Focus on W>1.6 GeV.** ***Fertile area for discovery.***

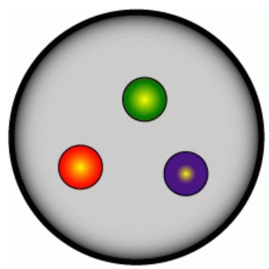
  – **Supported by quark models and recent data.**

Capstick and Roberts, PRD 58 (1998). *(SAPHIR, GRAAL, SPring−8, CLAS)*

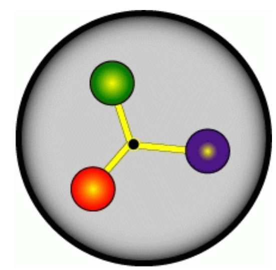
N* Resonances

**** or ***	$S_{11}(1535)$, $S_{11}(1650)$, $P_{11}(1440)$, $P_{11}(1710)$, $P_{13}(1720)$, $D_{13}(1520)$, $D_{13}(1700)$, $D_{15}(1675)$, $F_{15}(1680)$, $G_{17}(2190)$, $G_{19}(2250)$, $H_{19}(2220)$
** or *	$S_{11}(2090)$, $P_{11}(2100)$, $P_{13}(1900)$, $D_{13}(2080)$, $D_{15}(2200)$, $F_{15}(2000)$, $F_{17}(1990)$

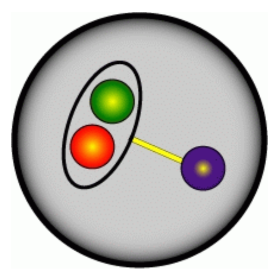
Effective Degrees of Freedom



CQM



CQM + flux tubes



Quark−diquark clustering

The Current Landscape

$N^* \to KY$					
State	PDG	B.R. ($K\Lambda$)	B.R. ($K\Sigma$)	$A_{1/2}$ (GeV$^{1/2}$)	$A_{3/2}$ (GeV$^{1/2}$)
$N^*(1650)\ S_{11}$	****	3-11%	-	0.053±0.016	
$N^*(1675)\ D_{15}$	****	<1%	-	0.019±0.008	0.015±0.009
$N^*(1680)\ F_{15}$	****	-	-	-0.015±0.006	0.133±0.012
$N^*(1700)\ D_{13}$	***	<3%	-	-0.018±0.013	-0.002±0.024
$N^*(1710)\ P_{11}$	***	5-25%	-	0.009±0.022	
$N^*(1720)\ P_{13}$	***	1-15%	-	0.018±0.03	-0.019±0.020
$N^*(1900)\ P_{13}$	**	-	-	-	-
$N^*(1990)\ F_{17}$	**	-	-	-	-
$N^*(2000)\ F_{15}$	**	-	-	-	-

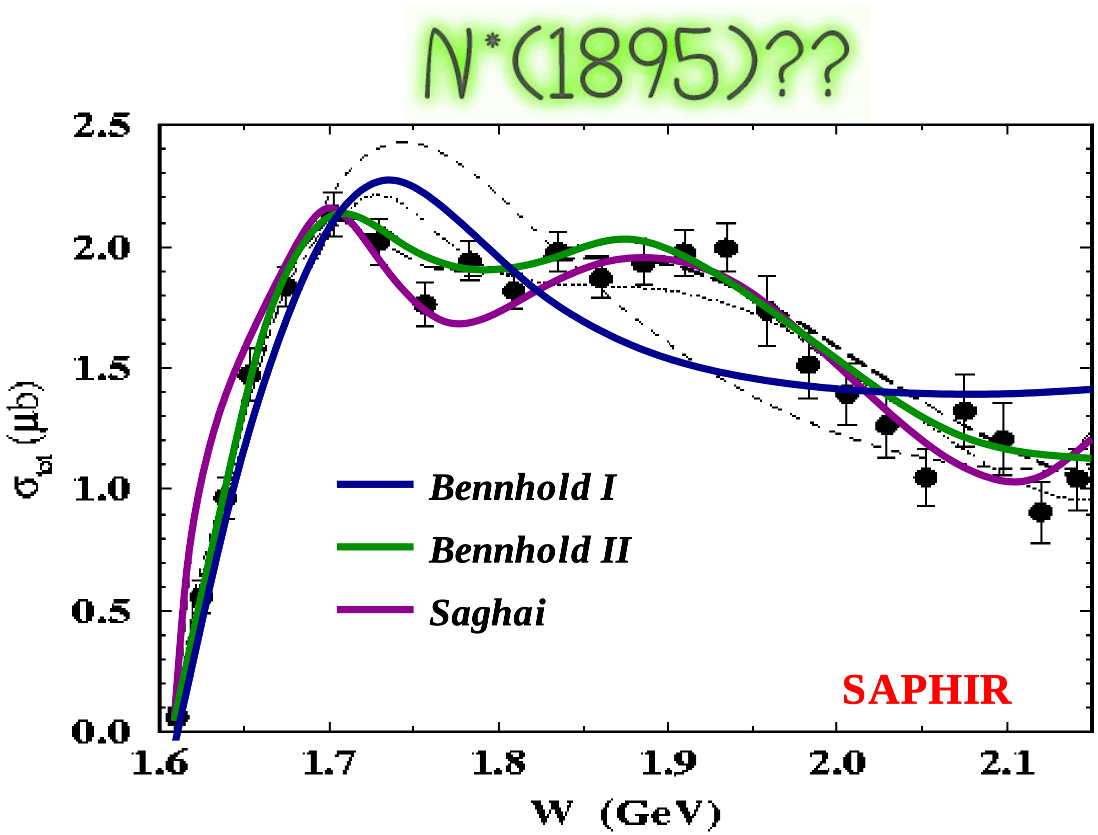
$\Delta^* \to K\Sigma$				
State	PDG	B.R. ($K\Sigma$)	$A_{1/2}$ (GeV$^{1/2}$)	$A_{3/2}$ (GeV$^{1/2}$)
$\Delta^*(1900)\ S_{31}$	**	-	?	
$\Delta^*(1905)\ F_{35}$	****	-	0.026±0.011	-0.045±0.020
$\Delta^*(1910)\ P_{31}$	****	-	0.003±0.014	
$\Delta^*(1920)\ P_{33}$	***	2.1%	?	?
$\Delta^*(1930)\ D_{35}$	***	-	-0.009±0.028	-0.018±0.028
$\Delta^*(1940)\ D_{33}$	*	-	?	?
$\Delta^*(1950)\ F_{37}$	****	-	-0.076±0.012	-0.097±0.010

We have significant room for improvement!!

Cross Sections

$\gamma + p \rightarrow K^+ + \Lambda$

Ref. B. Saghai
nucl−th/0105001



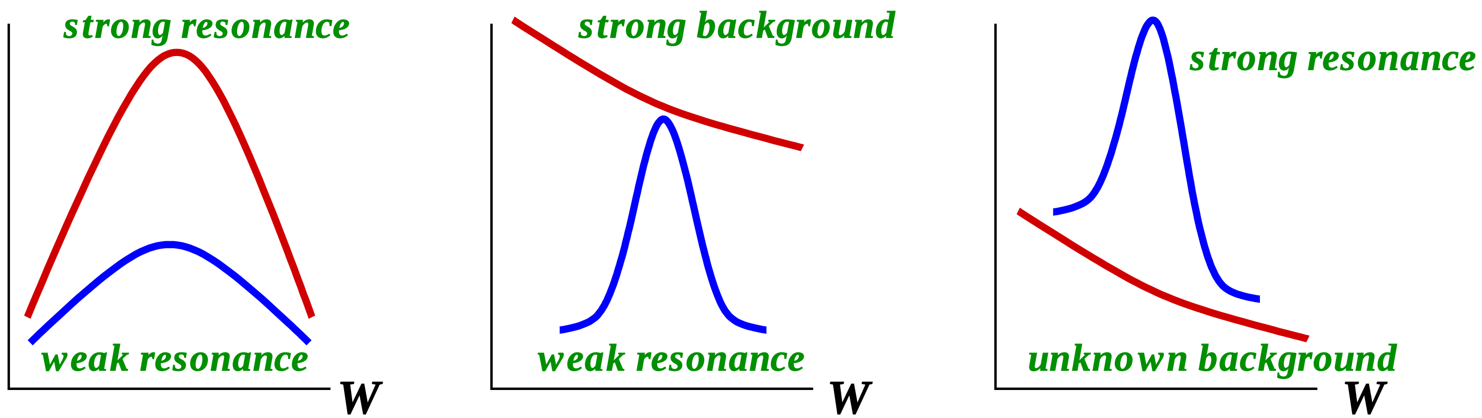
Bennhold I : Born terms
t: $K^*(892)$, $K_1(1270)$
s: $S_{11}(1650)$, $P_{11}(1710)$, $P_{13}(1720)$

Bennhold II: Bennhold I + $D_{13}(1895)$

Saghai: Bennhold I + u: $P_{01}(1810)$, $P_{03}(1890)$
Proper treatment of off-shell effects (for $s \geq 3/2$)

Polarization Observables

- **Most of our understanding about the reaction mechanism comes from unpolarized experiments.**
  - *This gives access only to limited information.*
- **Polarization provides information about the contributing amplitudes.**



- **Access underlying dynamics via both single and double polarization.**
  - $\vec{\gamma}^{(*)} + p \rightarrow K^{+} + Y$ — *Beam Asymmetry*
  - $\gamma^{(*)} + p \rightarrow K^{+} + \vec{Y}$ — *Induced Polarization*
  - $\vec{\gamma}^{(*)} + p \rightarrow K^{+} + \vec{Y}$ — *Transferred Polarization*

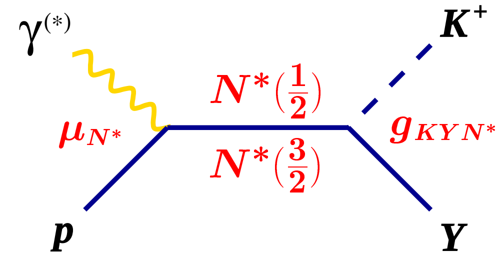
polarized target data coming too.

Hadrodynamic Models

- **Isobar models based on effective Lagrangian.**

  (Mart, Bennhold, Janssen)

- **Features primarily due to s−channel resonances.**
  - ***t−channel contains only K and K*.***
  - ***Coupling strengths set by fits to existing data.***
  - ***Parameters set by coupled−channels study.***
  - ***Recent addition of u−channel Y* resonances.***
- **Effective at low to moderate energies.**



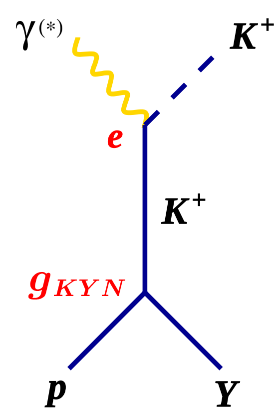
	BM		JB	
Resonance	$K^+\Lambda$	$K^+\Sigma^0$	$K^+\Lambda$	$K^+\Sigma^0$
$N^*(1650)$ (S_{11})	*	*	*	*
$N^*(1710)$ (P_{11})	*	*	*	*
$N^*(1720)$ (P_{13})	*	*	*	*
$N^*(1895)$ (D_{13})	*	*	*	*
$K^*(892)$	*	*	*	*
$K_1^*(1270)$	*	*	*	*
$\Lambda^*(1800)$ (S_{01})			*	
$\Lambda^*(1810)$ (P_{01})			*	
$\Delta^*(1900)$ (S_{31})		*		*
$\Delta^*(1910)$ (P_{31})		*		*

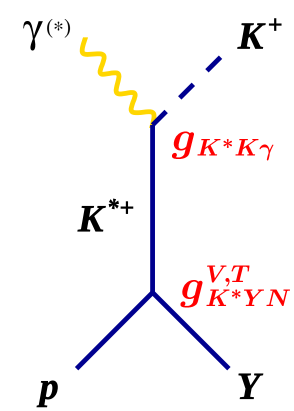
Regge Models

- **Models based on t−channel Regge exchange.**

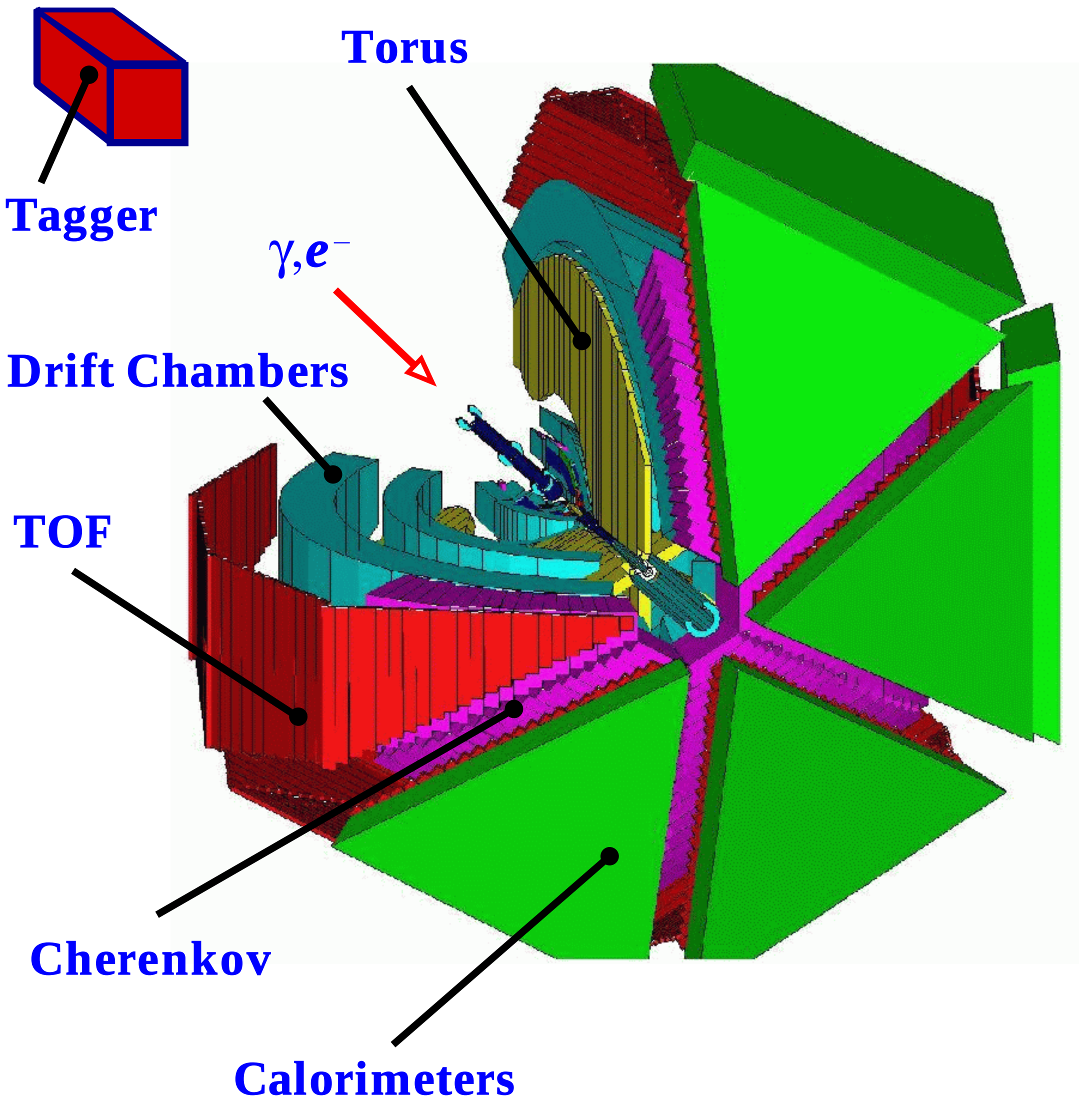
  (Guidal, Laget, Vanderhaeghen)

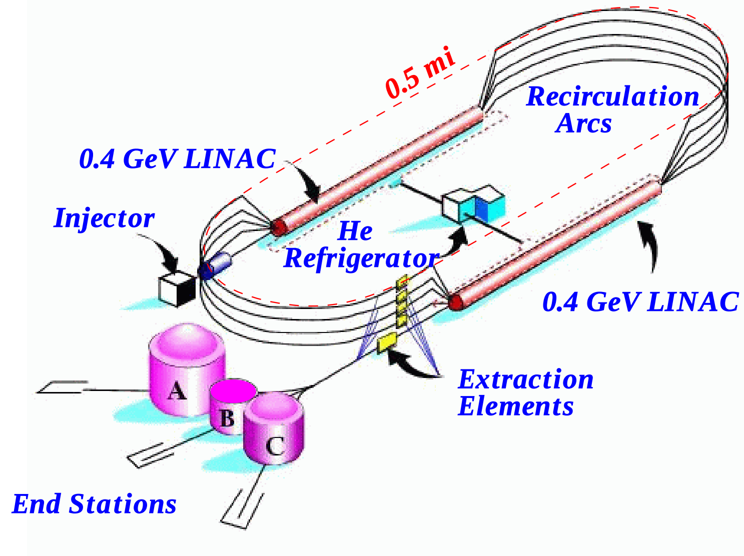
- **NO s−channel resonances included.**
- **Very few adjustable parameters.**
- **Effective at moderate to higher energies.**





CLAS Spectrometer





Characteristics:

Electron Coverage: $\theta : 15\text{–}50^{o}$

Hadron Coverage:

$\theta : 15\text{–}140^{o}, \ \phi : 80\% \ 2\pi$

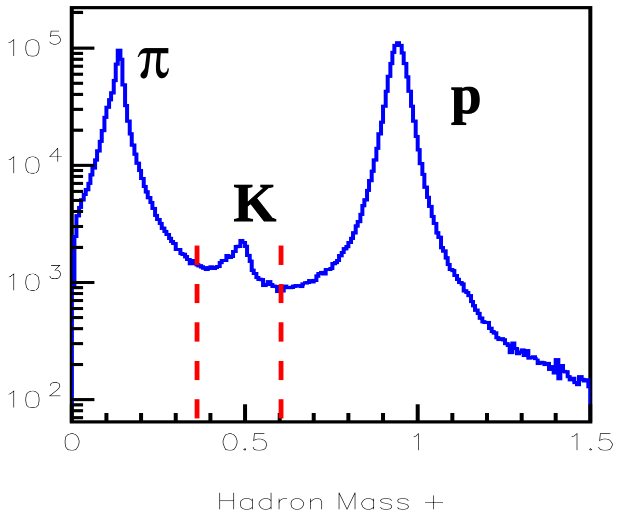
Resolution : $\Delta p/p \sim 1\text{–}2\%$
$\Delta\theta, \Delta\phi \sim 2$ mrad

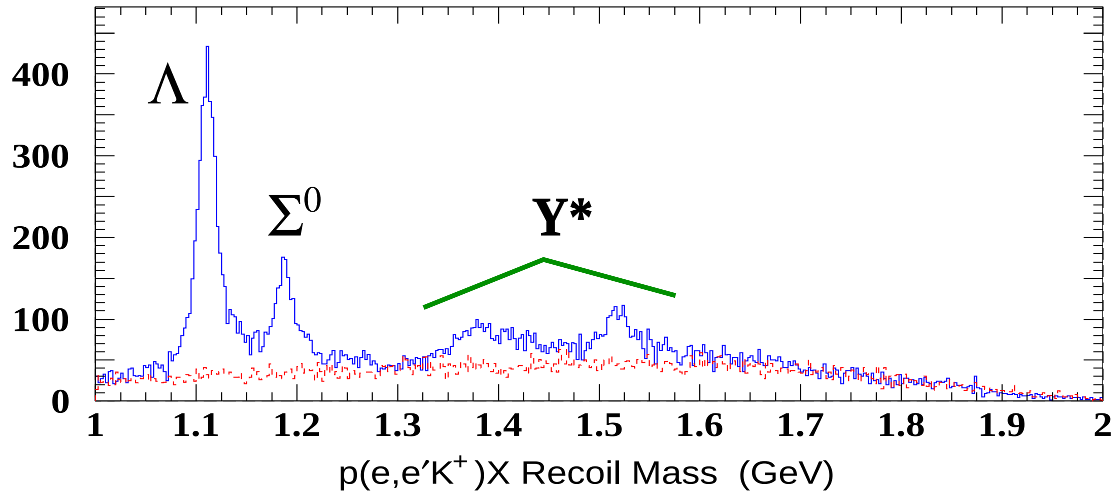
$$\mathcal{L} = 1 \times 10^{34} \ cm^{-2} sec^{-1}$$

$$\mathcal{F}_\gamma = 1 \times 10^{7}/s$$

Cross Section Extraction

Electroproduction example



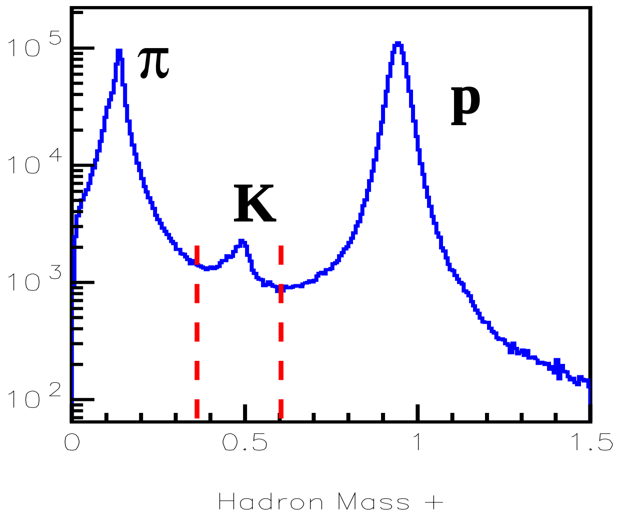


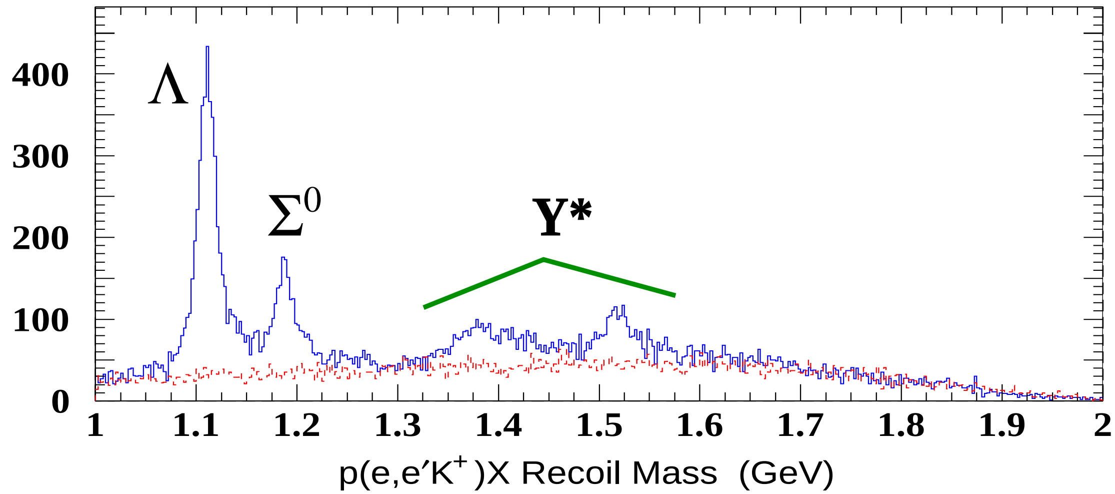
$$\frac{d^2\sigma_i}{d\Omega_K^*} = \frac{1}{\Gamma_v}\frac{1}{\Delta Q^2 \Delta W \Delta \cos\theta_K^* \Delta\phi}\frac{R_i N_i}{\eta_i}\frac{1}{N_0(N_A \rho t/M_t)}$$

- Signal & Background Fits
- Acceptance Corrections
- Radiative Corrections
- Live Time & Efficiency Corrections
- Systematic Studies (12%)
- Momentum Corrections
- Bin Centering Factors

Cross Section Extraction

Electroproduction example





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- Signal & Background Fits
- Systematic Studies (12%)
- Acceptance Corrections
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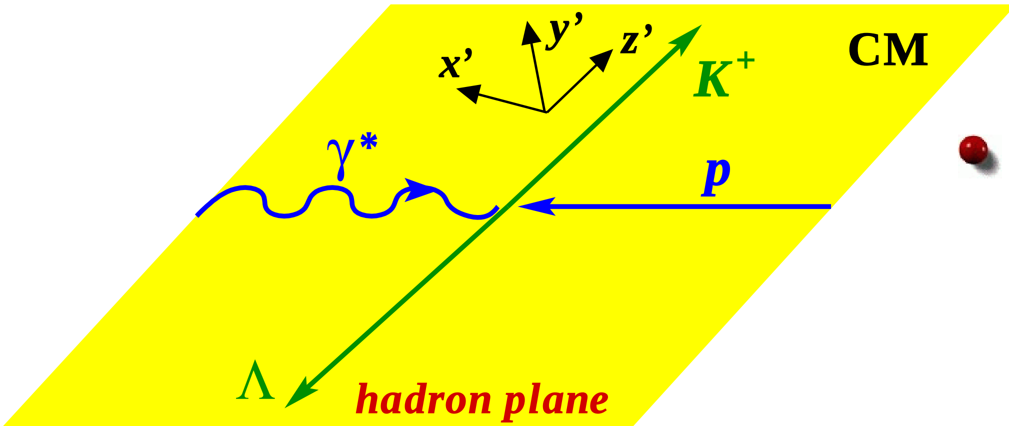
Polarization Extraction



- **Hyperon decays weakly via:**

$$\Lambda \rightarrow p\pi^-$$

The polarization of the Λ is "betrayed" by angular distribution of the proton.

$$\frac{dN_p^{\pm}}{d(\cos\theta_p^*)} = N^{\pm}[1 + \alpha P_\Lambda \cos\theta_p^*]$$

(Self-Analyzing Decay)

$$\vec{P}_\Lambda = \vec{P}^o \pm P_b \vec{P}'$$

Transferred

Induced

No polarimeter needed!

PHOTOPRODUCTION

Energy Distributions

$$\gamma + p \rightarrow K^+ + \Lambda$$

Sample of ~1400 CLAS points.

Forward angles	**Backward angles**
M=1950 MeV **Γ=100 MeV**	**M=1890 MeV** **Γ=200 MeV**

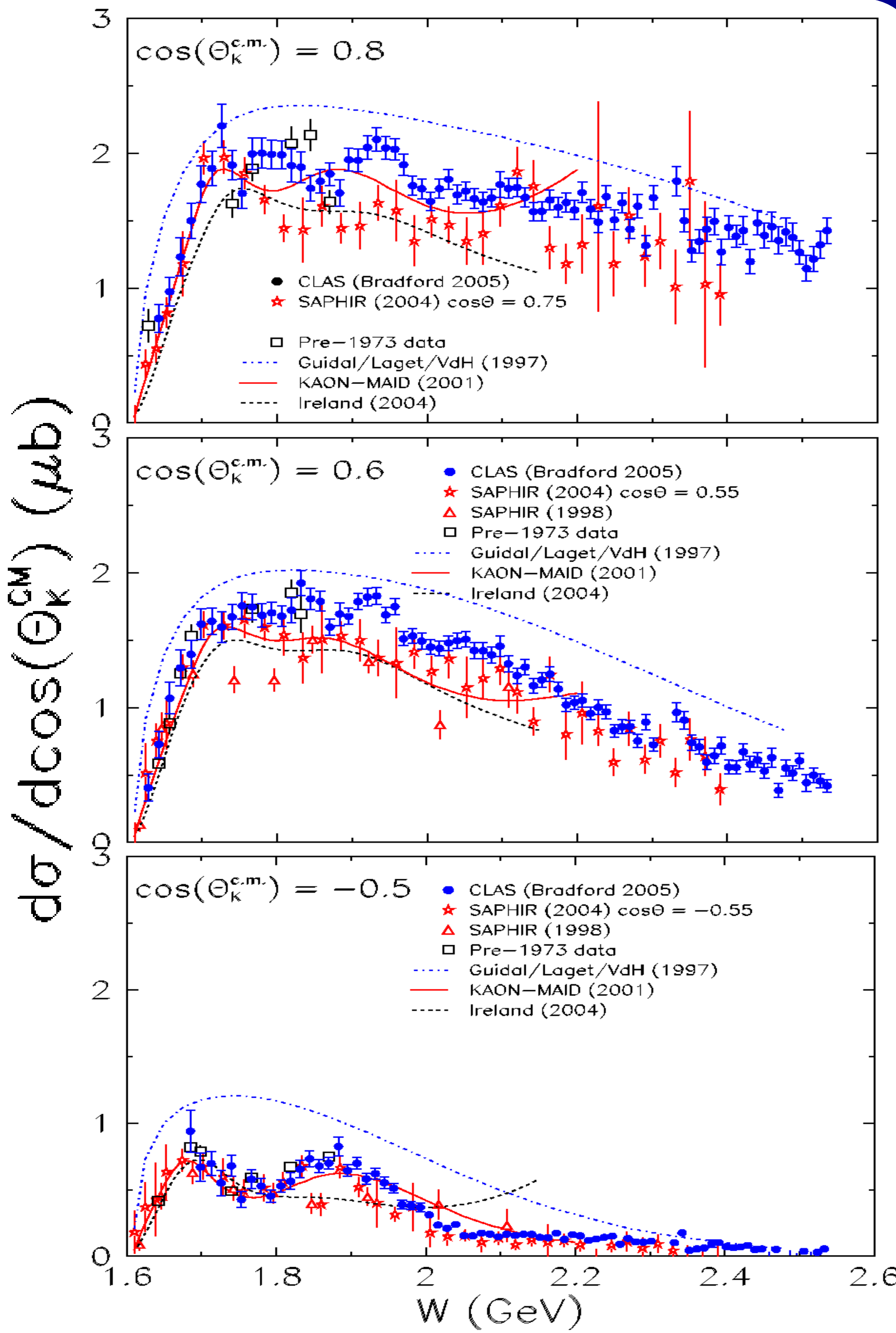
Guidal − 1999
Bennhold − 2002
Janssen − 2002

− Existing models perform poorly

But, NOT yet fit to this CLAS data!!

Agreement in CLAS K and Kp final states.

Bradford (CLAS), submitted to PRC (2005).



Energy Distributions

$$\gamma + p \rightarrow K^+ + \Sigma^0$$

Sample of ~1300 CLAS points.

One peak at 1.9 GeV with an angle−dependent shape.

Guidal − 1999
Bennhold − 2002
Janssen − 2002

− Existing models perform poorly

But, NOT yet fit to this CLAS data!!

Agreement in CLAS K and Kp final states.

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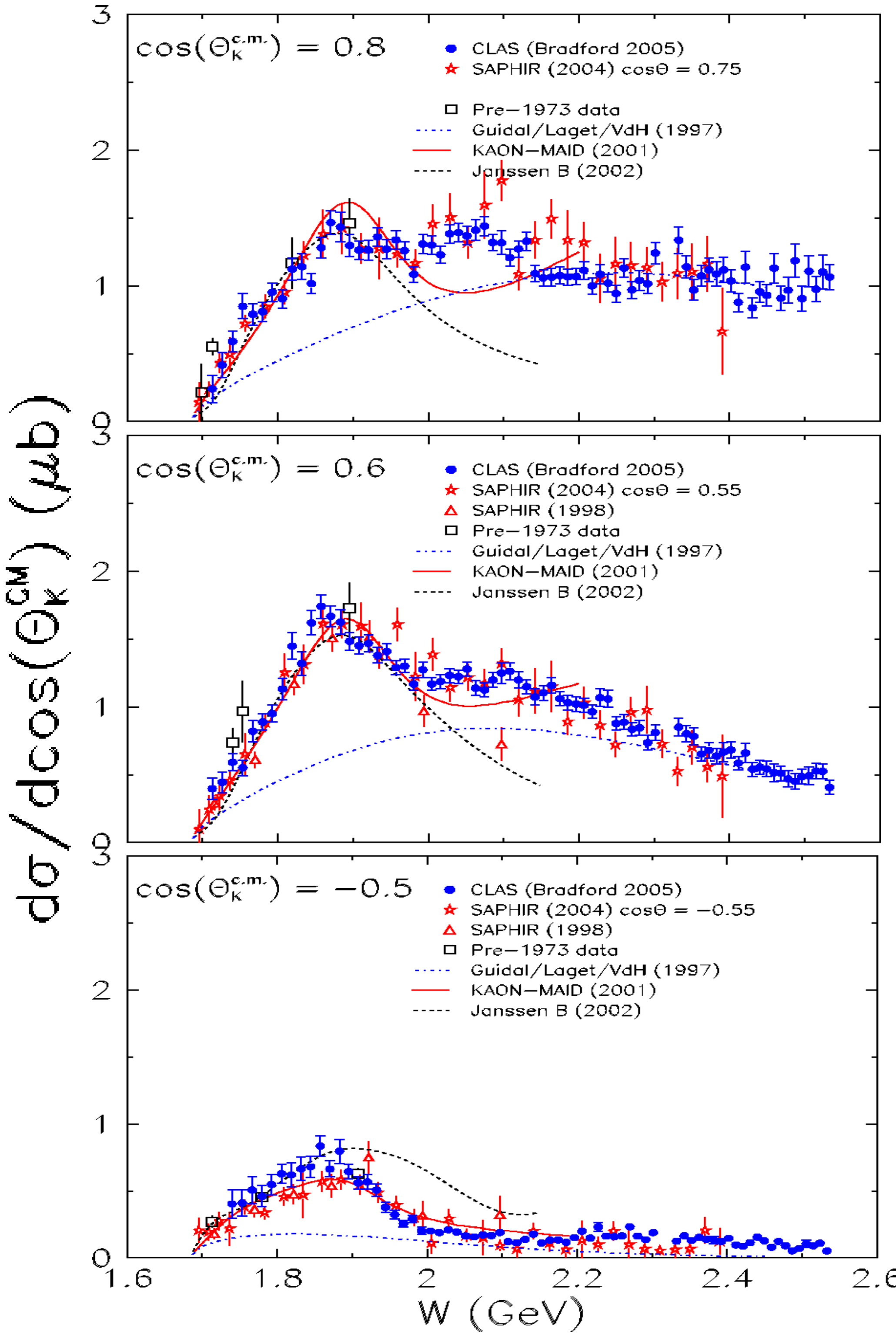
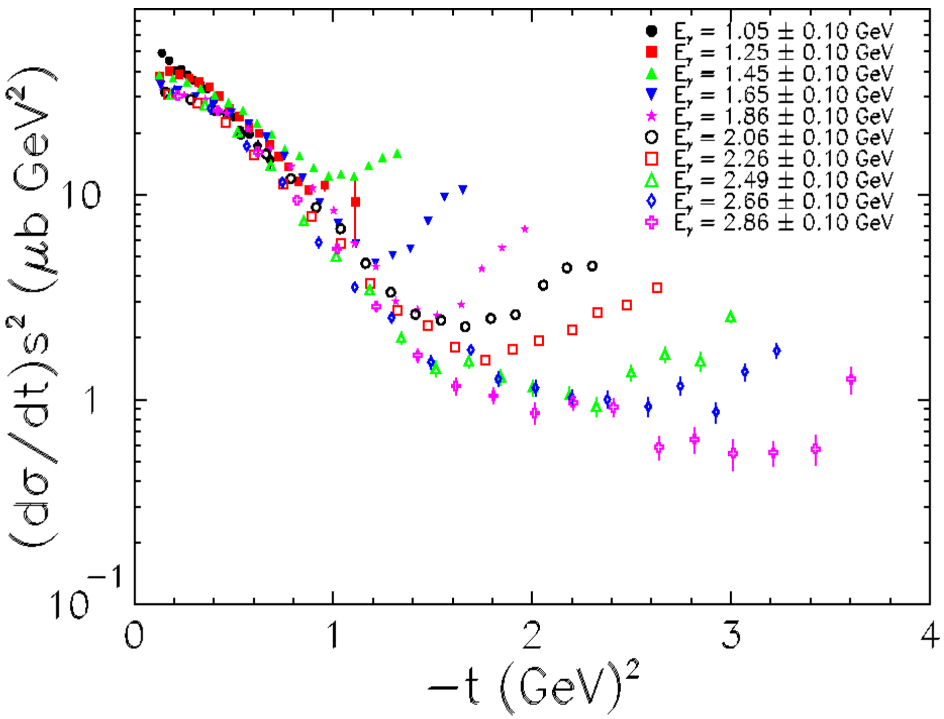


Cross Section Analysis

- **Within the Regge exchange picture:**

$$\frac{d\sigma}{dt} = \mathcal{D}(t)\left(\frac{s}{s_0}\right)^{2\alpha(t)-2} \quad \Rightarrow \quad \frac{d\sigma}{dt} \propto \frac{1}{s^2}$$

$$\gamma + p \rightarrow K^+ + \Lambda$$



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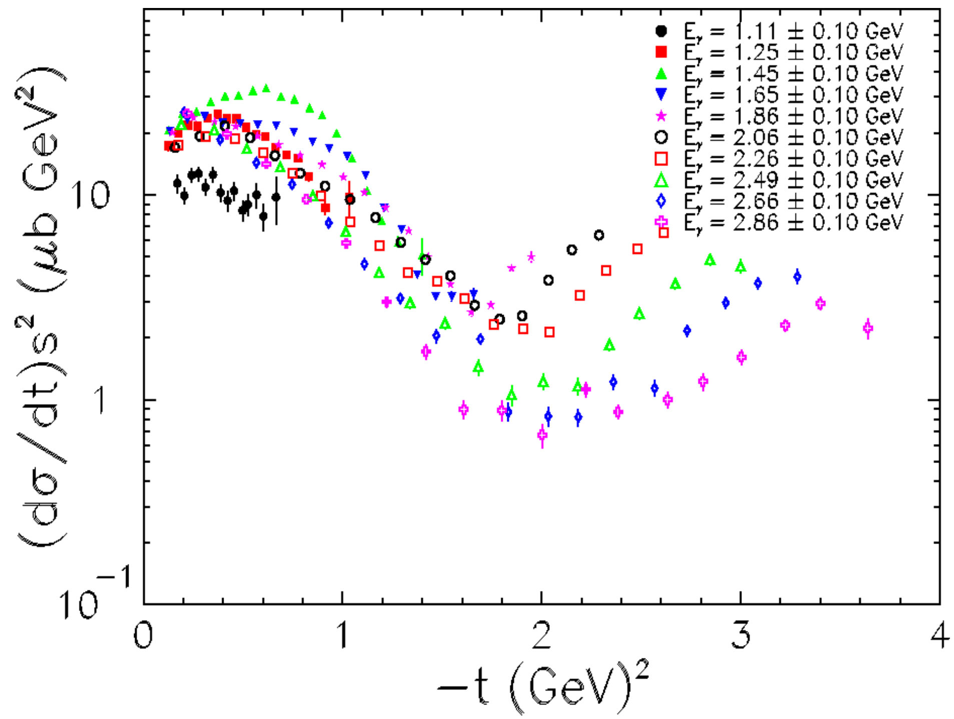
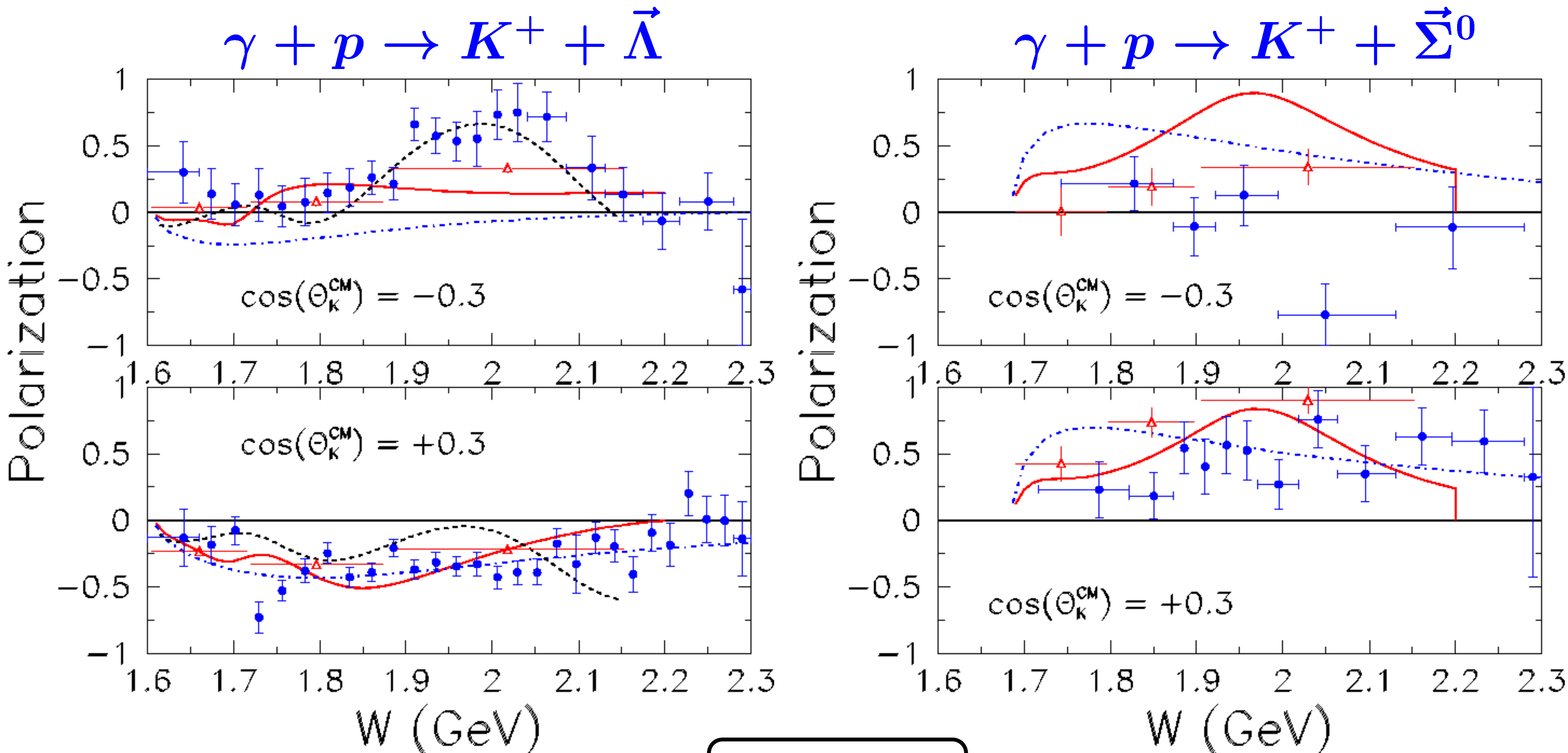


Bradford (CLAS), submitted to PRC (2005).

Induced Polarization



- Full CLAS data set
- SAPHIR data set

Guidal − 1999
Bennhold − 2002
Janssen − 2002

McNabb (CLAS), PRC 69, 042201 (R) (2004)

- Deviations apparent with models over full kinematics.

- Transferred polarization C_x, C_z (see Bradford talk).

Similar signatures to electroproduction

Higher−Level Analysis

Decays of Baryon Resonances into ΛK^+, $\Sigma^0 K^+$ and $\Sigma^+ K^0$

A.V. Sarantsev[1,2], V.A. Nikonov[1,2], A.V. Anisovich[1,2], E. Klempt[1], and U. Thoma[1,3]

[1] Helmholtz–Institut für Strahlen– und Kernphysik, Universität Bonn, Germany
[2] Petersburg Nuclear Physics Institute, Gatchina, Russia
[3] Physikalisches Institut, Universität Gießen, Germany

hep−ex/0506011

June 7, 2005

Abstract. Cross sections, beam asymmetries, and recoil polarisations for the reactions $\gamma p \to K^+\Lambda$; $\gamma p \to K^+\Sigma^0$, and $\gamma p \to K^0\Sigma^+$ have been measured by the SAPHIR, CLAS, and LEPS collaborations with high statistics and good angular coverage for centre-of-mass energies between 1.6 and 2.3 GeV. The combined analysis of these data with data from π and η photoproduction reveals evidence for new baryon resonances in this energy region. A new P_{11} state with mass 1840 MeV and width 140 MeV was observed contributing to most of the fitted reactions. The data demand the presence of two D_{13} states at 1870 and 2170 MeV.

PACS: 11.80.Et, 11.80.Gw, 13.30.-a, 13.30.Ce, 13.30.Eg, 13.60.Le 14.20.Gk

Observable	$N_{\rm data}$	χ^2	$\chi^2/N_{\rm data}$	Weight
$\sigma(\gamma p \to \Lambda K^+)$	720	804	1.12	4
$\sigma(\gamma p \to \Lambda K^+)$	770	1282	1.67	2
$P(\gamma p \to \Lambda K^+)$	202	374	1.85	1
$\Sigma(\gamma p \to \Lambda K^+)$	45	62	1.42	15
$\sigma(\gamma p \to \Sigma^0 K^+)$	660	834	1.27	1
$\sigma(\gamma p \to \Sigma^0 K^+)$	782	2446	3.13	1
$P(\gamma p \to \Sigma^0 K^+)$	95	166	1.76	1
$\Sigma(\gamma p \to \Sigma^0 K^+)$	45	20	0.46	35
$\sigma(\gamma p \to \Sigma^+ K^0)$	48	104	2.20	2
$\sigma(\gamma p \to \Sigma^+ K^0)$	120	109	0.91	5
$\sigma(\gamma p \to p\pi^0)$	1106	1654	1.50	8
$\sigma(\gamma p \to p\pi^0)$	861	2354	2.74	3.5
$\Sigma(\gamma p \to p\pi^0)$	469	1606	3.43	2
$\Sigma(\gamma p \to p\pi^0)$	593	1702	2.87	2
$\sigma(\gamma p \to n\pi^+)$	1583	4524	2.86	1
$\sigma(\gamma p \to p\eta)$	667	608	0.91	35
$\sigma(\gamma p \to p\eta)$	100	158	1.60	7
$\Sigma(\gamma p \to p\eta)$	51	114	2.27	10
$\Sigma(\gamma p \to p\eta)$	100	174	1.75	10

Resonance	$\Gamma_{N\eta}/\Gamma_{N\pi}$	$\Gamma_{\Lambda K}/\Gamma_{N\pi}$	$\Gamma_{\Sigma K}/\Gamma_{N\pi}$
$N(1520)D_{13}$	$1.5\cdot10^{-3}$	0	0
$N(1675)D_{15}$	0.05	0.05	0
$N(1680)F_{15}$	$1\cdot10^{-3}$	$1\cdot10^{-4}$	0
$N(1700)D_{13}$	0.80	0.07	$5\cdot10^{-3}$
$N(1720)P_{13}$	0.80	0.20	0.01
$N(1840)P_{11}$	0.25	0.11	0.80
$N(1870)D_{13}$	2.0	0.28	1.6
$N(2000)F_{15}$	0.04	$5\cdot10^{-3}$	$3\cdot10^{-3}$
$N(2070)D_{15}$	0.30	$8\cdot10^{-3}$	0.015
$N(2170)D_{13}$	0.04	0.17	0.14
$N(2200)P_{13}$	2.0	0.18	0.11
$\Delta(1700)D_{33}$			$2.5\cdot10^{-3}$
$\Delta(1920)P_{33}$			0.04
$\Delta(1940)D_{33}$			0.75
$\Delta(1950)F_{37}$			0.01

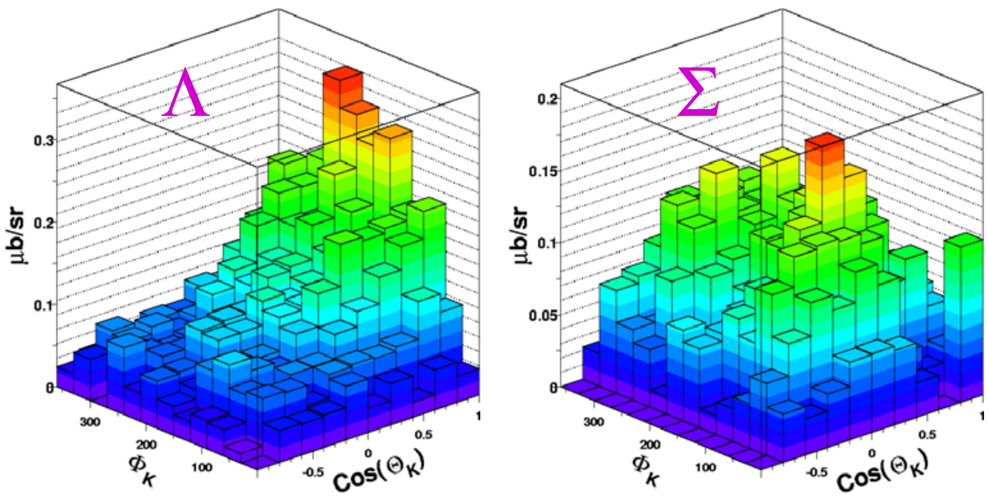
- **Need to reduce ambiguities and improve fits with electroproduction data.**

ELECTROPRODUCTION

Structure Functions in Electoproduction

$$\frac{d^4\sigma}{dQ^2 dW d\Omega_K^*} = \Gamma_v \left[\sigma_T + \epsilon\sigma_L + \epsilon\sigma_{TT}\cos 2\Phi + \sqrt{2\epsilon(\epsilon+1)}\sigma_{LT}\cos\Phi\right]$$

$$\sigma_i = f(Q^2, W, \cos\theta_K^*) \text{ only}$$



- For each bin in W, Q^2, $\cos\theta_K^*$ perform fit of the form:

$$\sigma = A + B\cos 2\Phi + C\cos\Phi$$

- Provide tomography of structure functions over full kinematic space of the nucleon resonance region.

$$Q^2 : 0.5 \rightarrow 3.5 \text{ GeV}^2 \quad W : 1.6 \rightarrow 2.4 \text{ GeV}$$

Full coverage in K^+ solid angle

Structure Functions in Electoproduction

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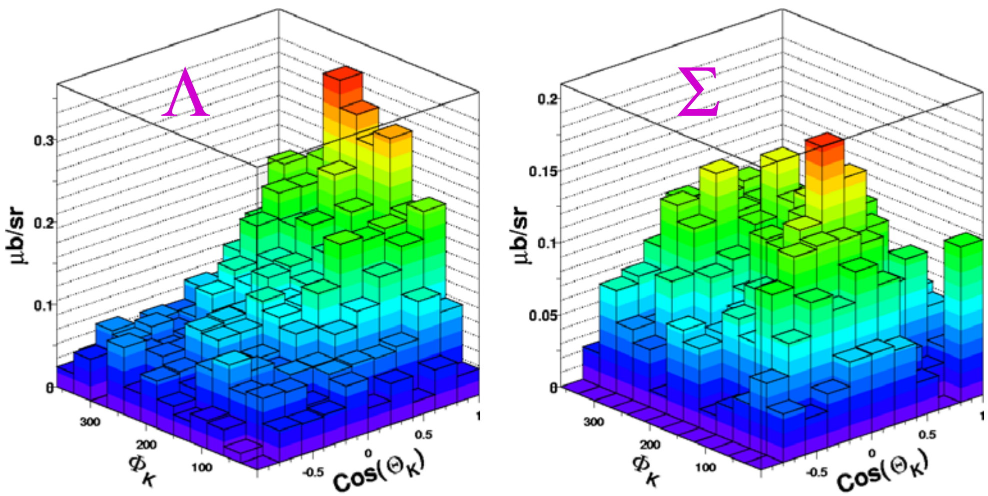

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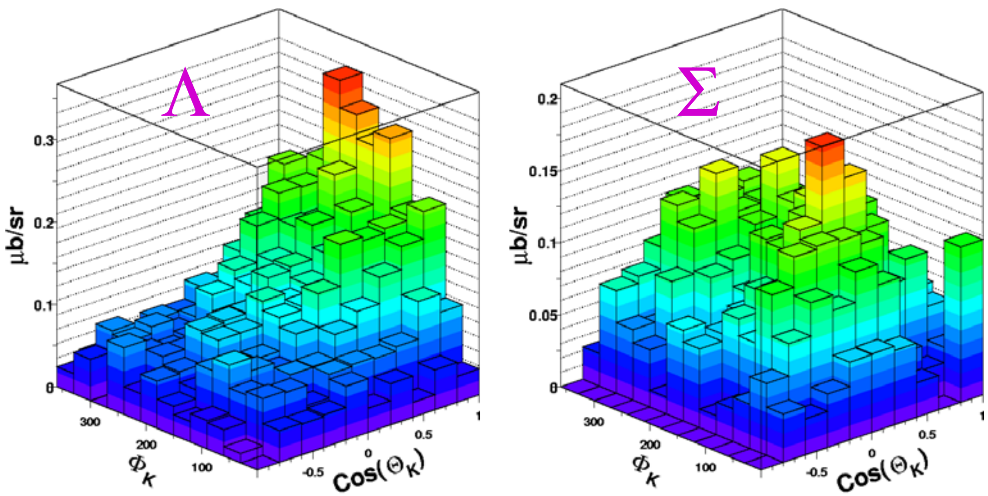

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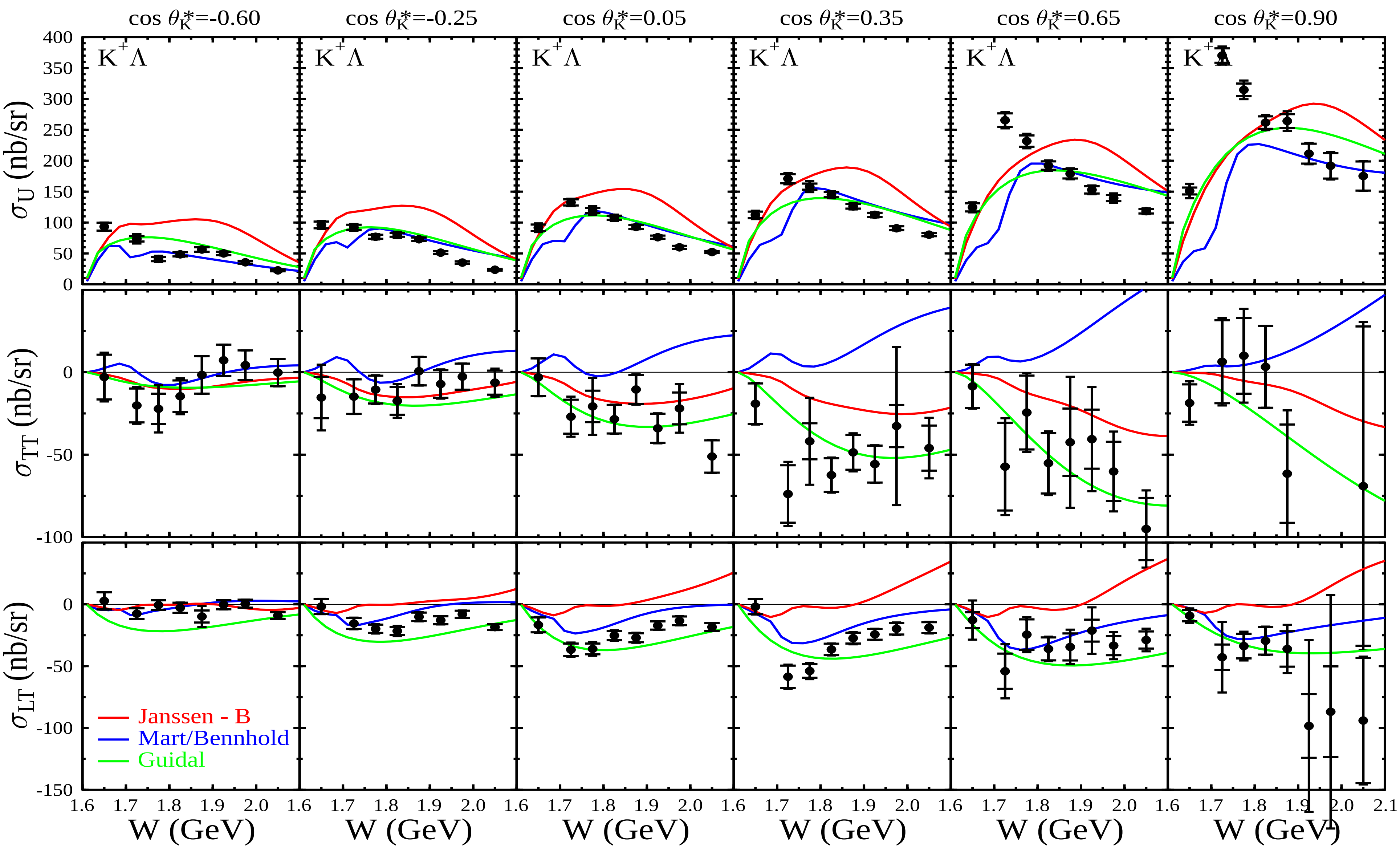
$$Q^2 : 0.5 \rightarrow 3.5\ \text{GeV}^2 \qquad W : 1.6 \rightarrow 2.4\ \text{GeV}$$

Full coverage in K^+ solid angle

Electroproduction Cross Sections

$ep \to e'K^+\Lambda$

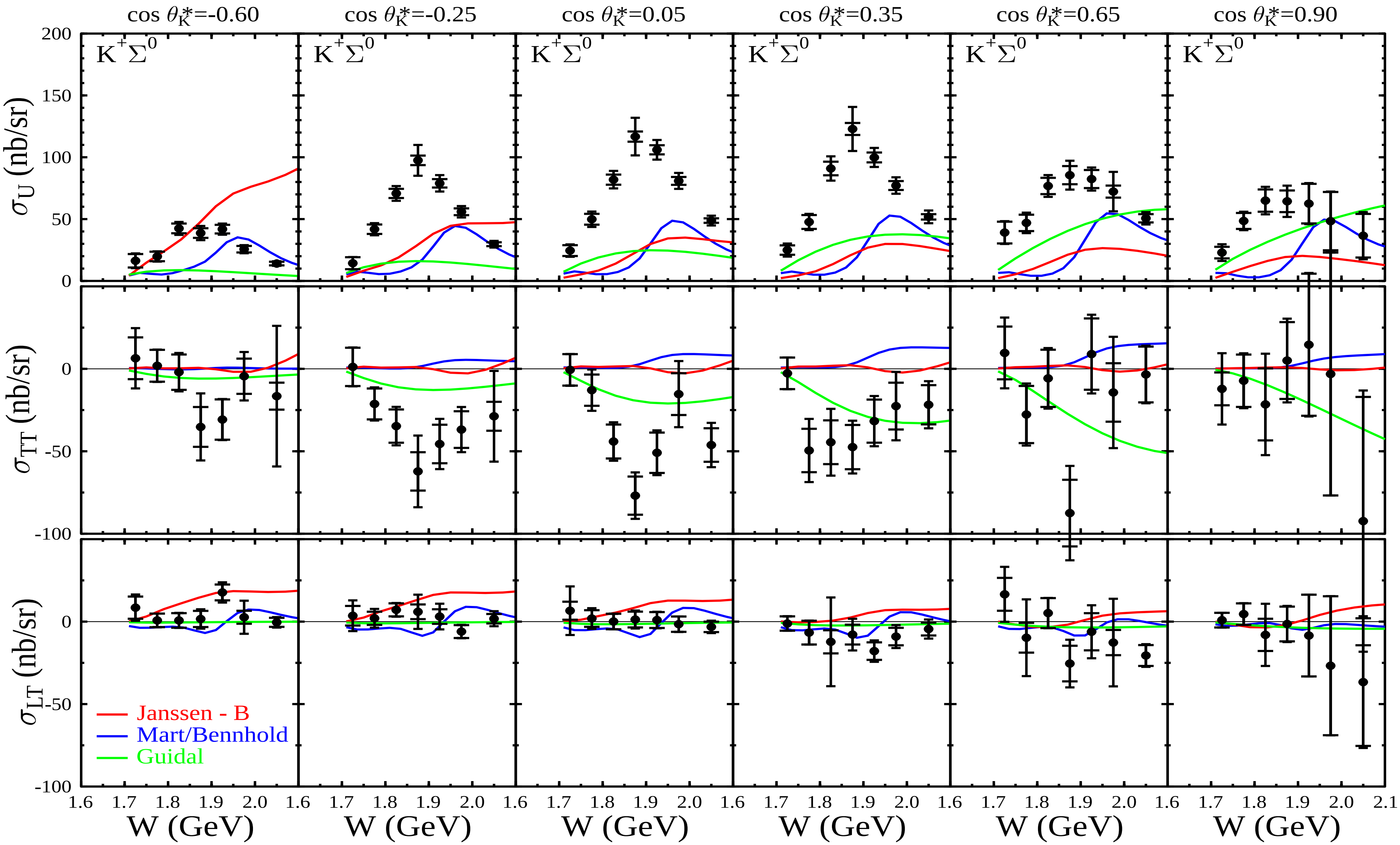


$Q^2 = 0.65\ (\mathrm{GeV/c})^2$

CLAS, to be submitted (2005).

Electroproduction Cross Sections

$ep \to e'K^+\Sigma^0$



CLAS, to be submitted (2005).

$Q^2 = 0.65\ (\mathrm{GeV/c})^2$

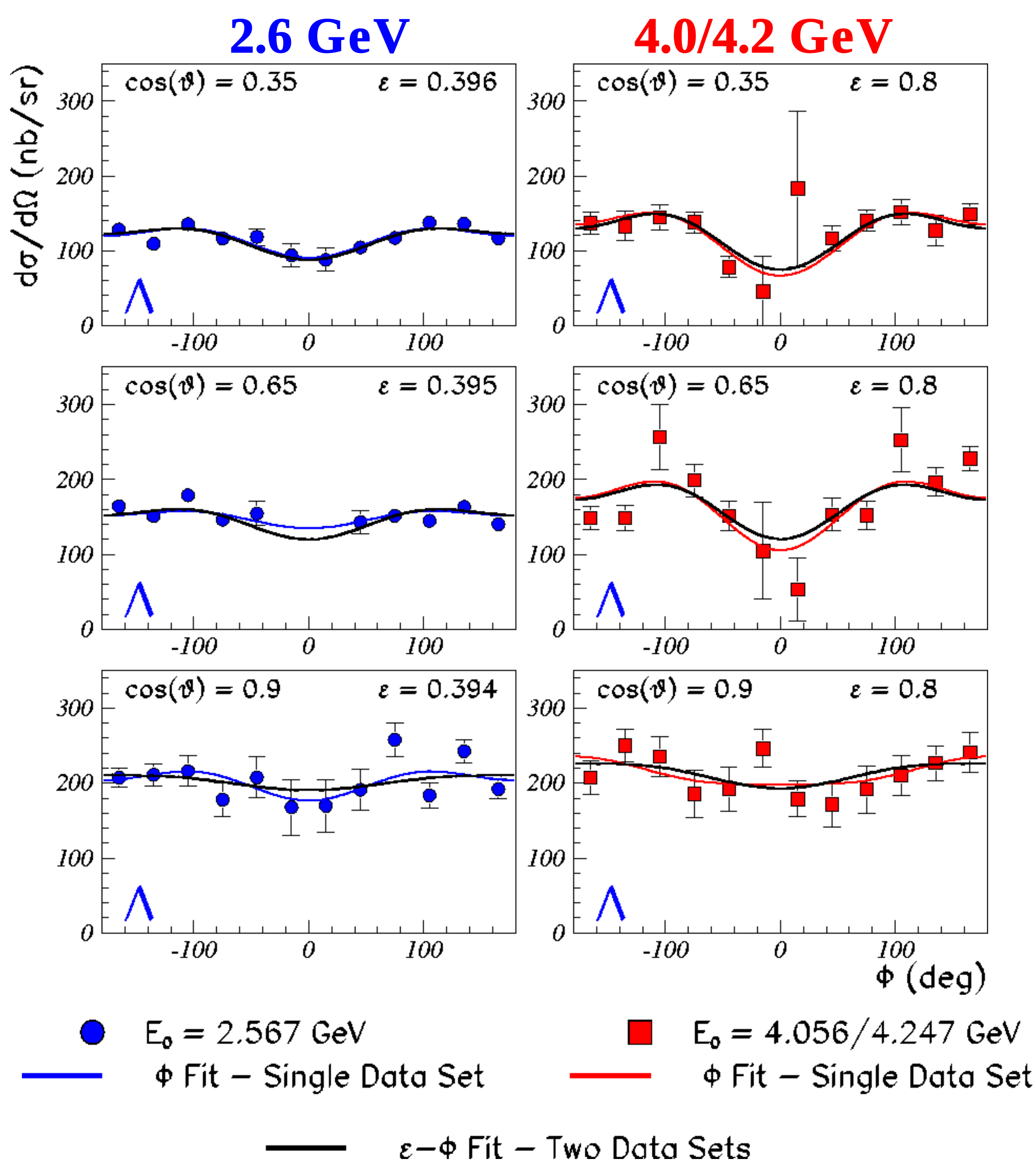
L/T Separation I

- **L and T structure functions are typically extracted using Rosenbluth approach.**

With CLAS we can also perform a simultaneous fit that constrains L, T, LT, and TT structure functions.

$$\sigma_i = f(Q^2, W, \cos\theta_K^*) \text{ only}$$

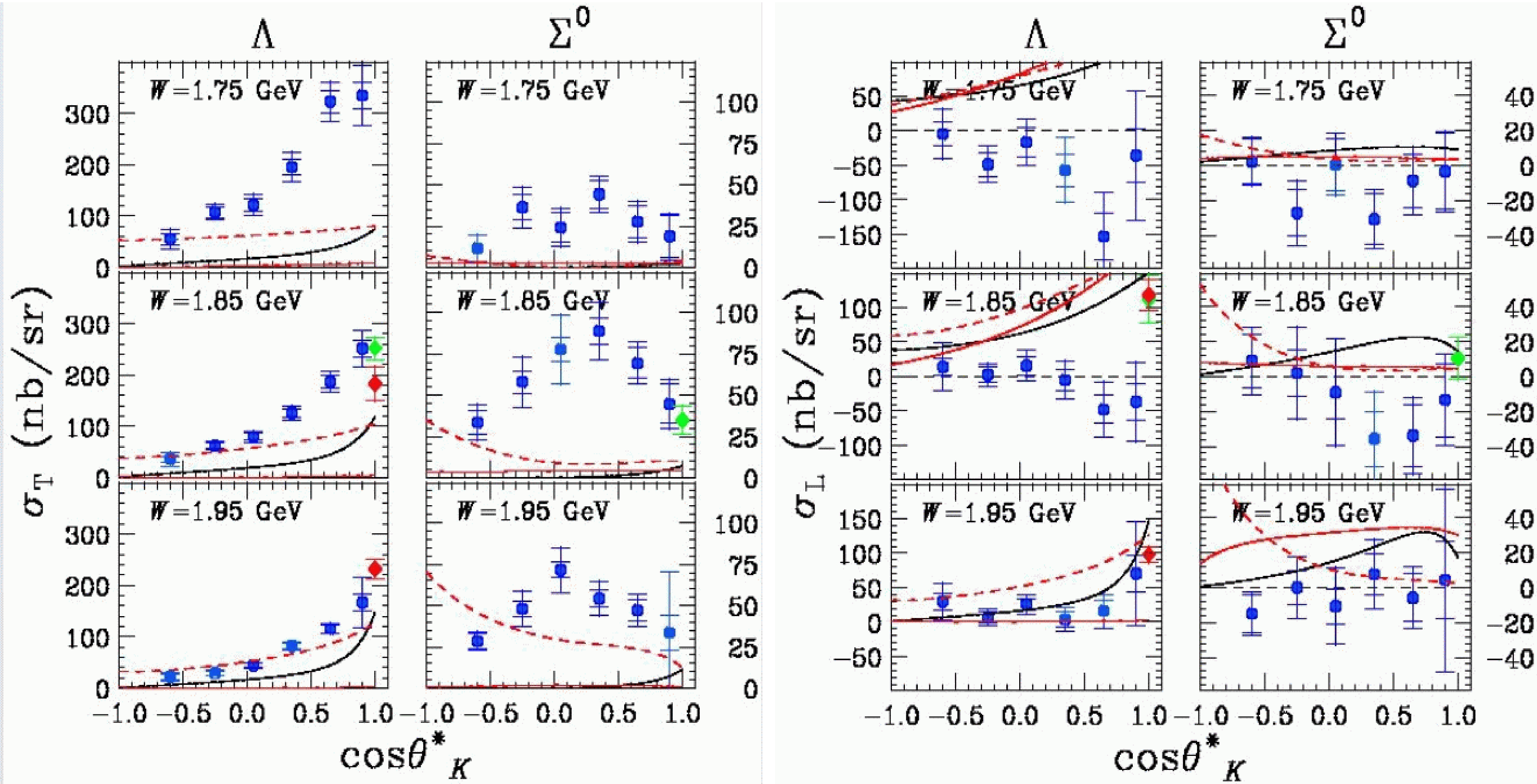
Reduces systematics!



$$W = 1.85 \text{ GeV}, \; Q^2 = 1.0 \text{ GeV}^2$$

L/T Separation I

PRELIMINARY



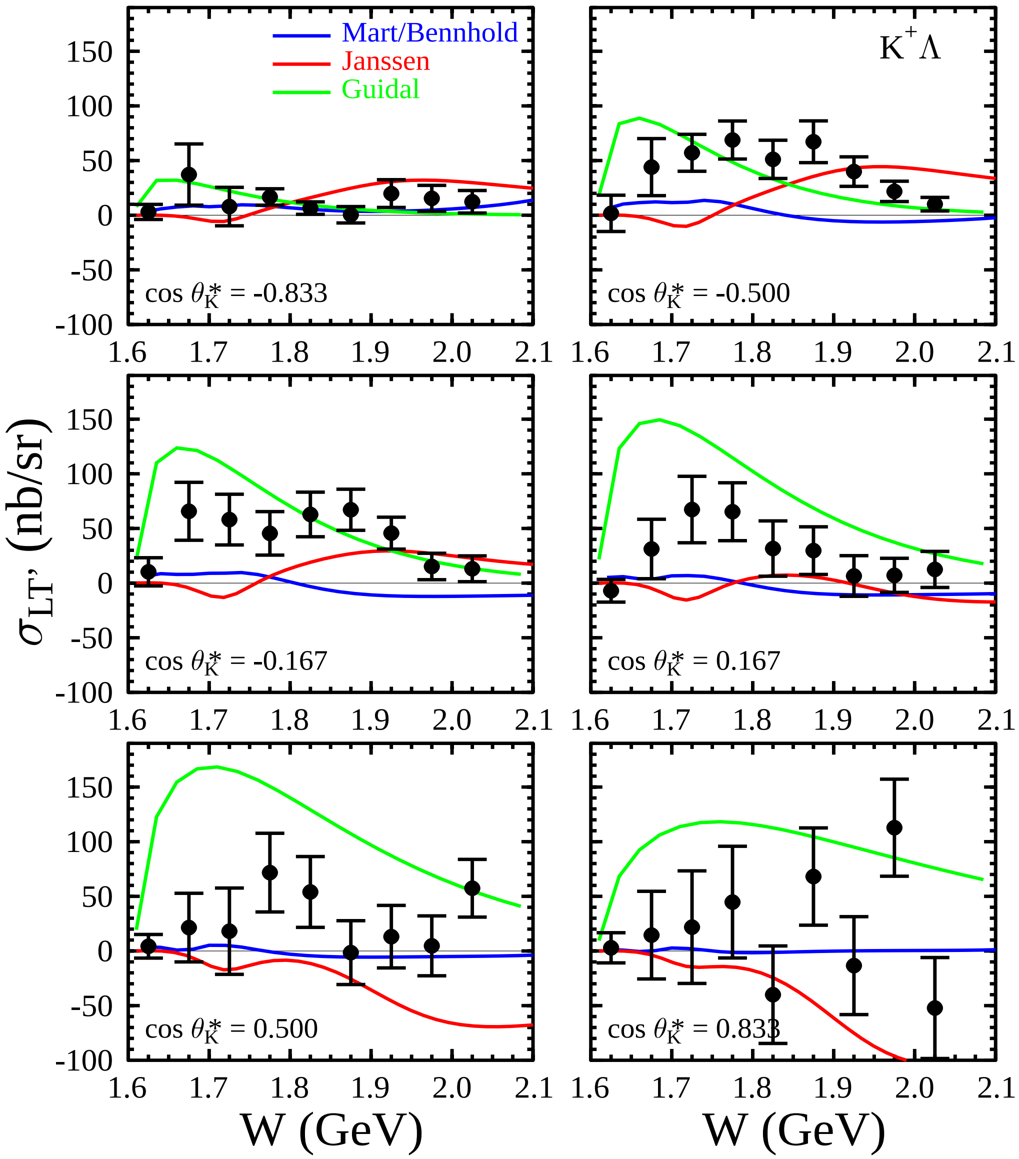
◆ **− Mohring (Hall C)**
◆ **− Markowitz (Hall A)**

CLAS, to be submitted (2005).

Fifth Structure Function

$\vec{e} + p \rightarrow e' + K^+ + \Lambda$

- **Measure polarized beam asymmetry to extract fifth structure function.**



$$A_{LT'} = \frac{1}{P_e}\frac{N^+ - N^-}{N^+ + N^-}$$
$$= \frac{1}{\sigma_0}\sqrt{2\epsilon_L(1-\epsilon)}\;\sigma_{LT'}\sin\Phi$$

Calculations from:

Mart/Bennhold

Janssen

Guidal

⇒ **Substantial differences in the reaction dynamics.**

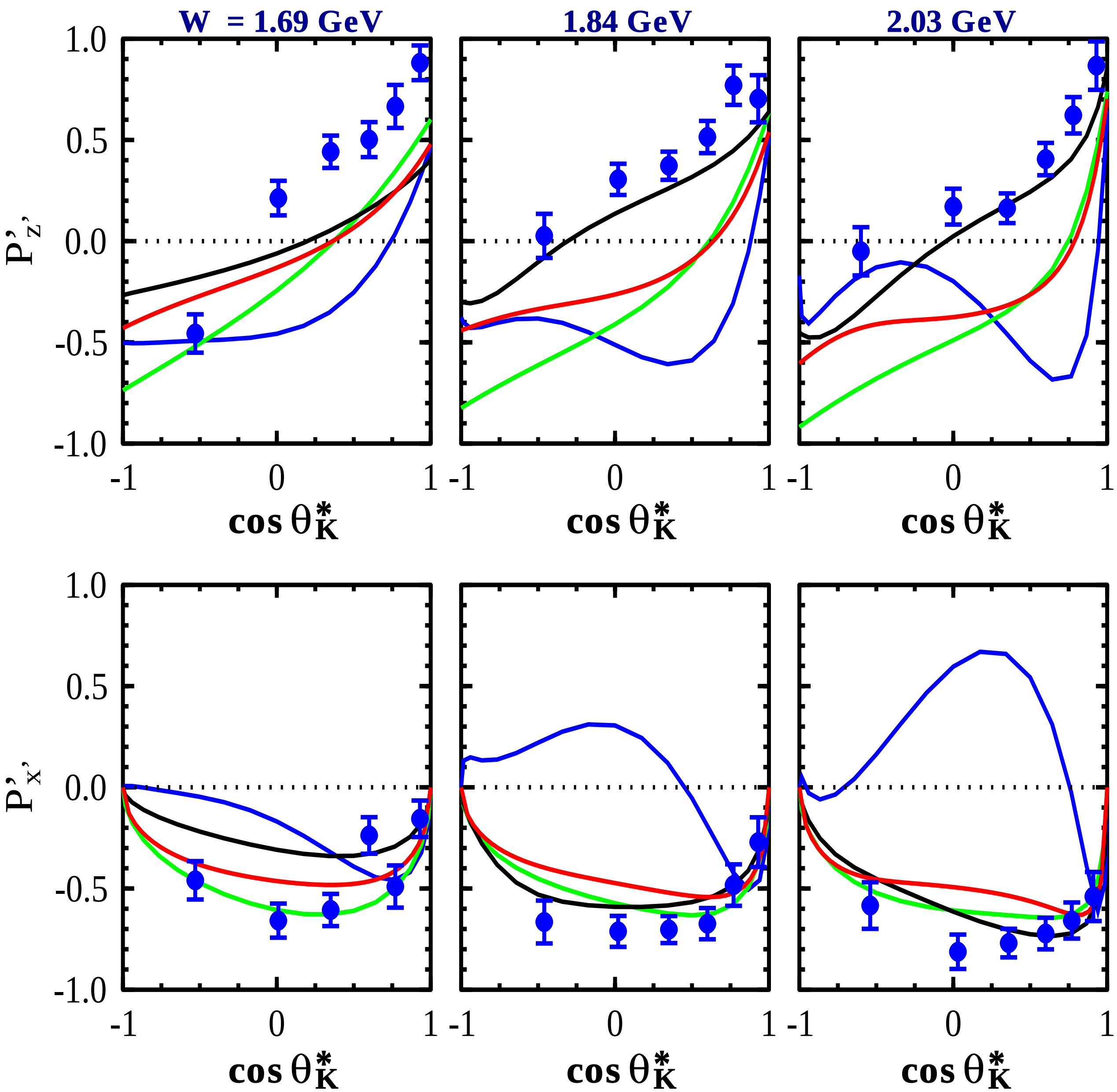
2.567 GeV $Q^2 = 0.70\ (GeV/c)^2$

Nasseripour (CLAS), to be submitted (2005).

Transferred Polarization

$\vec{e} + p \rightarrow e' + K^+ + \vec{\Lambda}$

(x',y',z') system



Williams − 1992
Bennhold − 2002
Janssen − 2002
Guidal − 1999

Resonance	WJC92	BM02	J02
$N^*(1650)$	*	*	*
$N^*(1710)$	*	*	*
$N^*(1720)$		*	*
$N^*(1895)$		*	*
$K^*(892)$	*	*	*
$K_1(1270)$	*	*	*
$\Lambda(1405)$	*		
$\Lambda(1800)$			*
$\Lambda(1810)$			*

2.567 GeV
Summed over Q^2, Φ

Carman (CLAS), PRL 90, 131804 (2003)

L/T Separation II

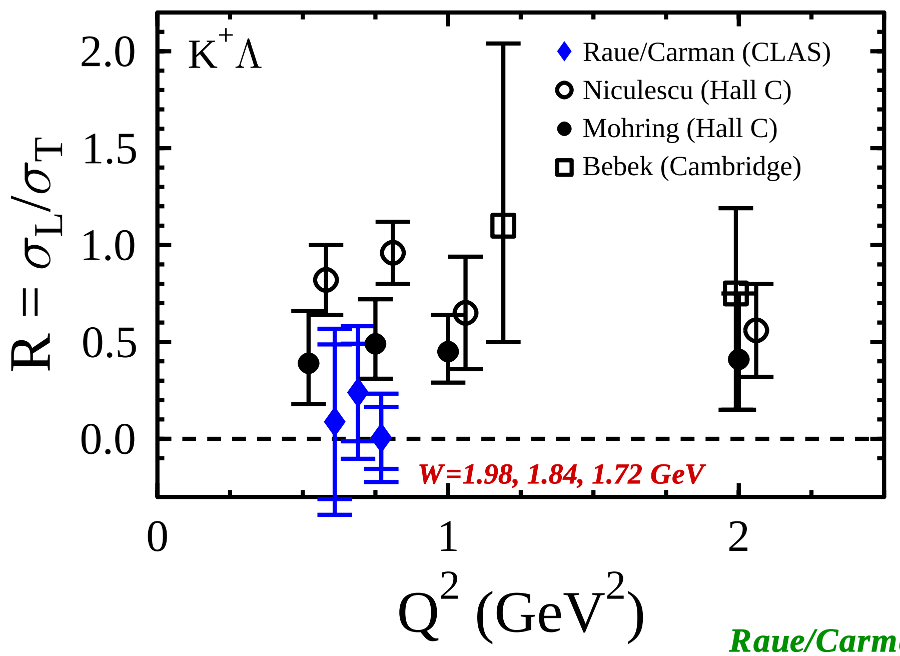
$\vec{e} + p \rightarrow e' + K^+ + \vec{\Lambda}$

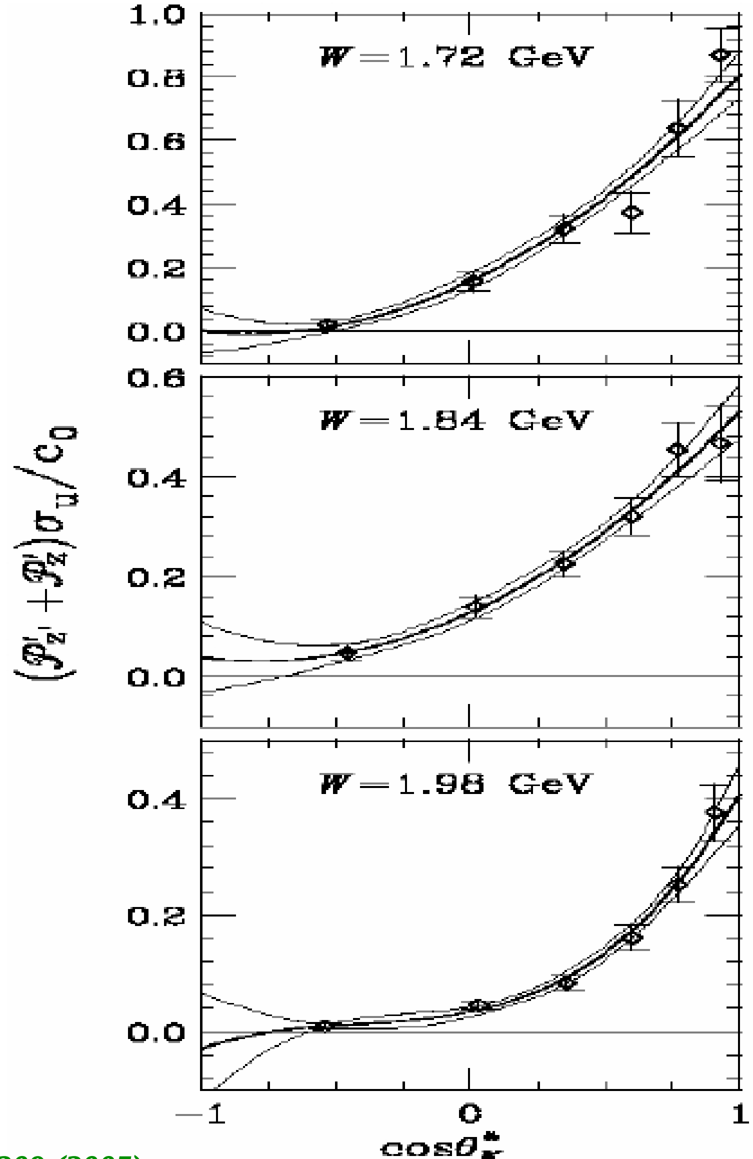
- **P' data can be used to extract the ratio σ_L/σ_T.**

  → **A complementary approach!**

- Extrapolating to $\theta^*_K = 0$:

$$R = \frac{\sigma_L}{\sigma_T} = \frac{1}{\epsilon}\left(\frac{c_0}{\mathcal{P}'_{z'}} - 1\right)$$





Raue/Carman, PRC 71, 065209 (2005)

Summary/ Conclusions

- **The Hall B strangeness physics program:**
  - **Designed to measure cross sections and all combinations of beam, target, and recoil polarization states.**
    - *Precision data -- broad kinematic coverage*
  - **Sensitive to high−mass baryons (>1.6 GeV) with large K−Y couplings and large photocoupling amplitudes.**
- **So far we have found:**
  - **Suggestive evidence of resonant structures in the data.**
    - *Both photo− and electroproduction*
  - **Existing theoretical models do not describe the data well in our kinematics.**
  - **Polarization data is quite versatile and useful to study.**
  - **Work needed to incorporate these data into the models.**
    - *Opportunity for significant new constraints*

Backup Slides

Formalism

$$\frac{d\sigma}{d\Omega_{E'} d\Omega_K^* dE'} = \Gamma_v \frac{d\sigma_v}{d\Omega_K^*}$$

(For unpolarized target)

$$\frac{d\sigma_v}{d\Omega_K^*} = \sigma_0 \left[1 + h\ A_{TL'} + \vec{S} \cdot \vec{P}^0\ +\ h\ (\vec{S} \cdot \vec{P}')\right]$$

Unpolarized Cross Section

$$\sigma_0 = \mathcal{K}(R_T^{00} + \epsilon_L R_L^{00} + \epsilon R_{TT}^{00} \cos 2\Phi + \sqrt{2\epsilon_L(1+\epsilon)}\ R_{TL}^{00} \cos\Phi)$$

$$A_{TL'} = \frac{\mathcal{K}}{\sigma_0} \sqrt{2\epsilon_L(1-\epsilon)}\ R_{TL'}^{00} \sin\Phi$$

Polarized beam

$$\begin{pmatrix} P_{x'}^0 \\ P_{y'}^0 \\ P_{z'}^0 \end{pmatrix} = \frac{\mathcal{K}}{\sigma_0} \begin{pmatrix} \sqrt{2\epsilon_L(1+\epsilon)}\ R_{TL}^{x'0} \sin\Phi + \epsilon R_{TT}^{x'0} \sin 2\Phi \\ R_T^{y'0} + \epsilon_L R_L^{y'0} + \sqrt{2\epsilon_L(1+\epsilon)}\ R_{TL}^{y'0} \cos\Phi + \epsilon R_{TT}^{y'0} \cos 2\Phi \\ \sqrt{2\epsilon_L(1+\epsilon)}\ R_{TL}^{z'0} \sin\Phi + \epsilon R_{TT}^{z'0} \sin 2\Phi \end{pmatrix}$$

Induced polarization

$$\begin{pmatrix} P'_{x'} \\ P'_{y'} \\ P'_{z'} \end{pmatrix} = \frac{\mathcal{K}}{\sigma_0} \begin{pmatrix} \sqrt{2\epsilon_L(1-\epsilon)}\ R_{TL'}^{x'0} \cos\Phi + \sqrt{1-\epsilon^2}\ R_{TT'}^{x'0} \\ \sqrt{2\epsilon_L(1-\epsilon)}\ R_{TL'}^{y'0} \sin\Phi \\ \sqrt{2\epsilon_L(1-\epsilon)}\ R_{TL'}^{z'0} \cos\Phi + \sqrt{1-\epsilon^2}\ R_{TT'}^{z'0} \end{pmatrix}$$

Transferred polarization

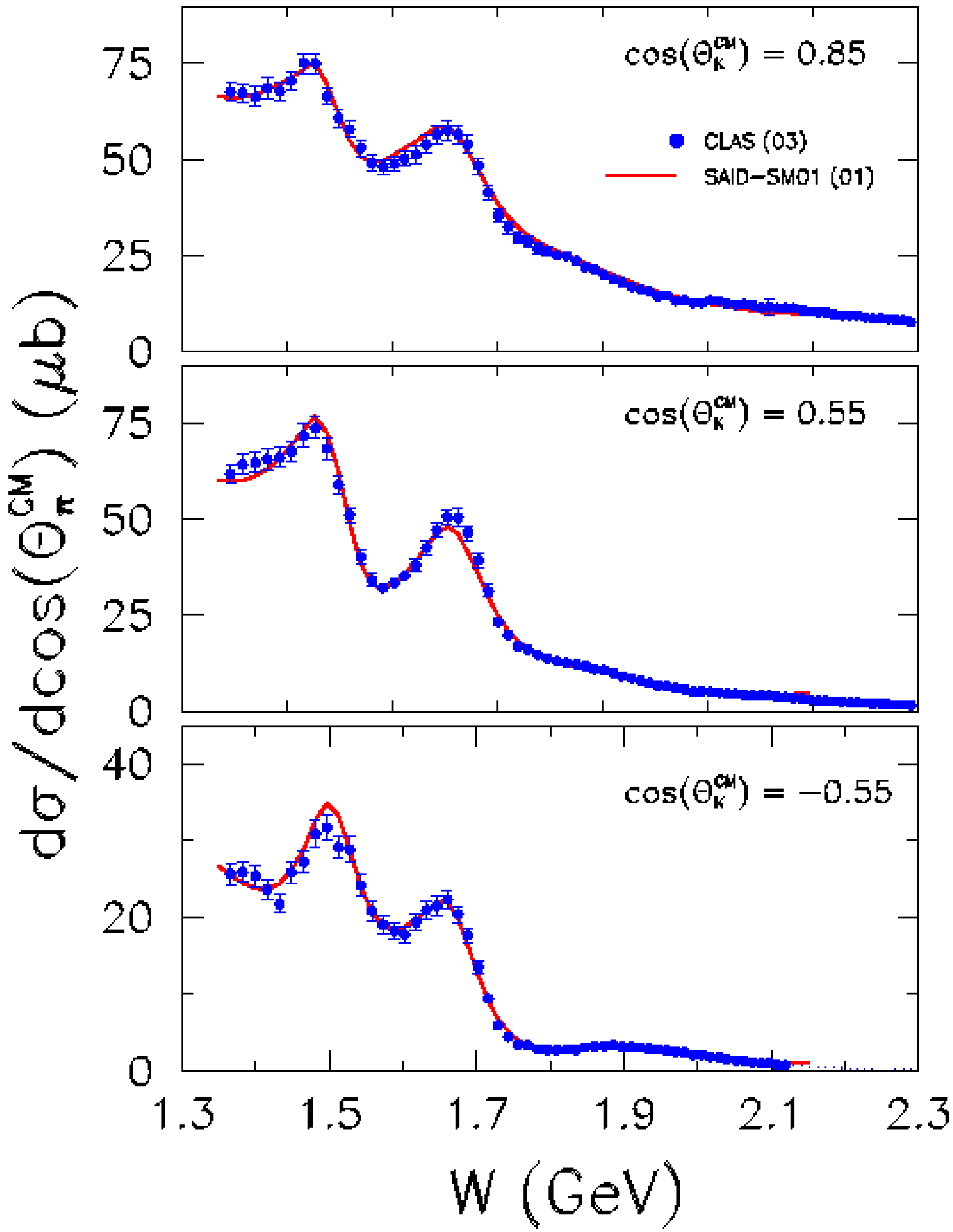
Normalization Check

$$\gamma + p \rightarrow \pi^+ + n$$

CLAS data normalized to pion production.

(photoproduction)

A sampling of the comparison.

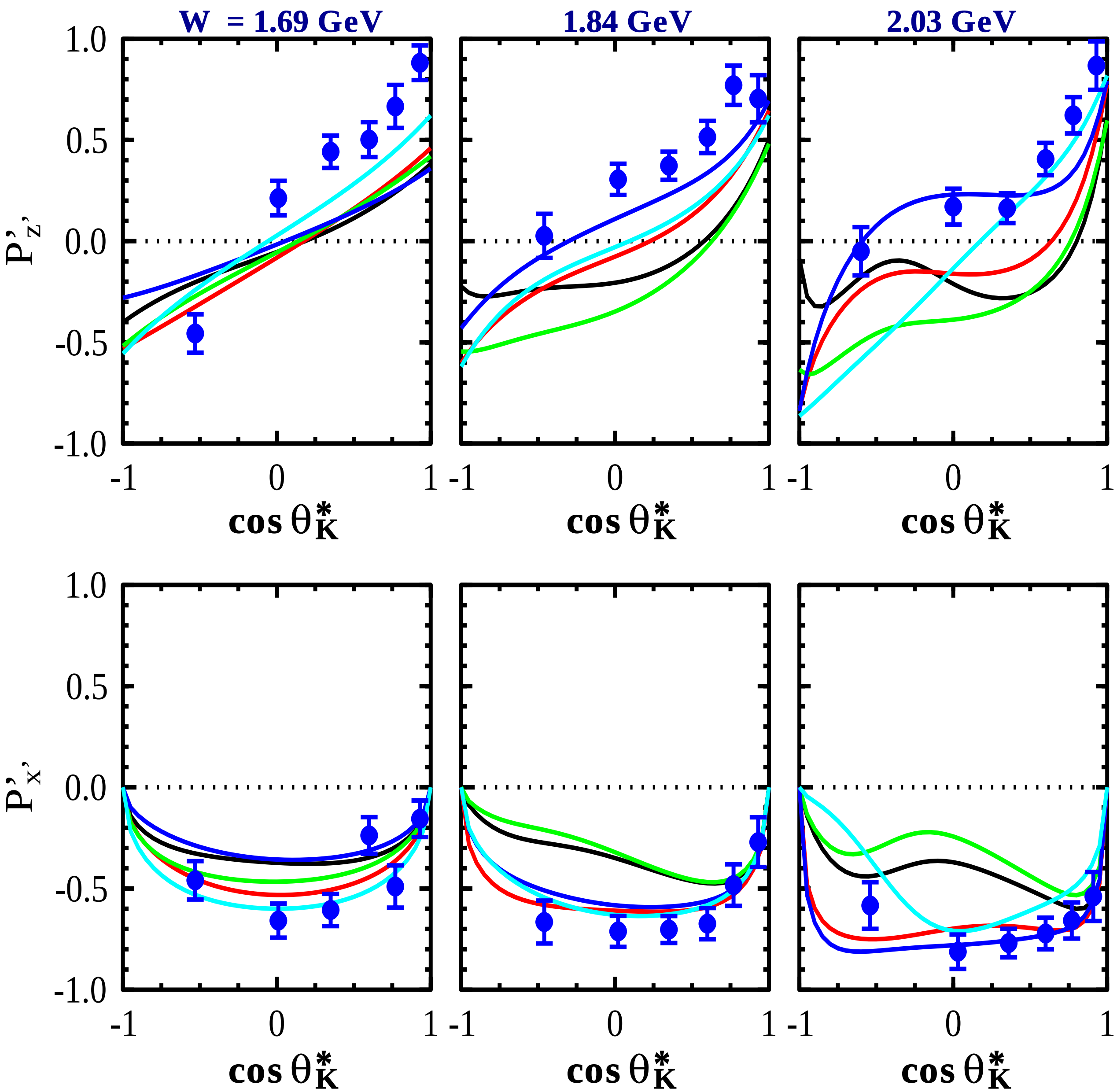


R.A. Schumacher and J. McNabb

Transferred Polarization

$\vec{e} + p \rightarrow e' + K^+ + \vec{\Lambda}$

(x',y',z') system



Janssen − 2002

No 1.9 GeV resonance
S11(1895)
P11(1895)
P13(1895)
D13(1895)

Model fit to existing data:

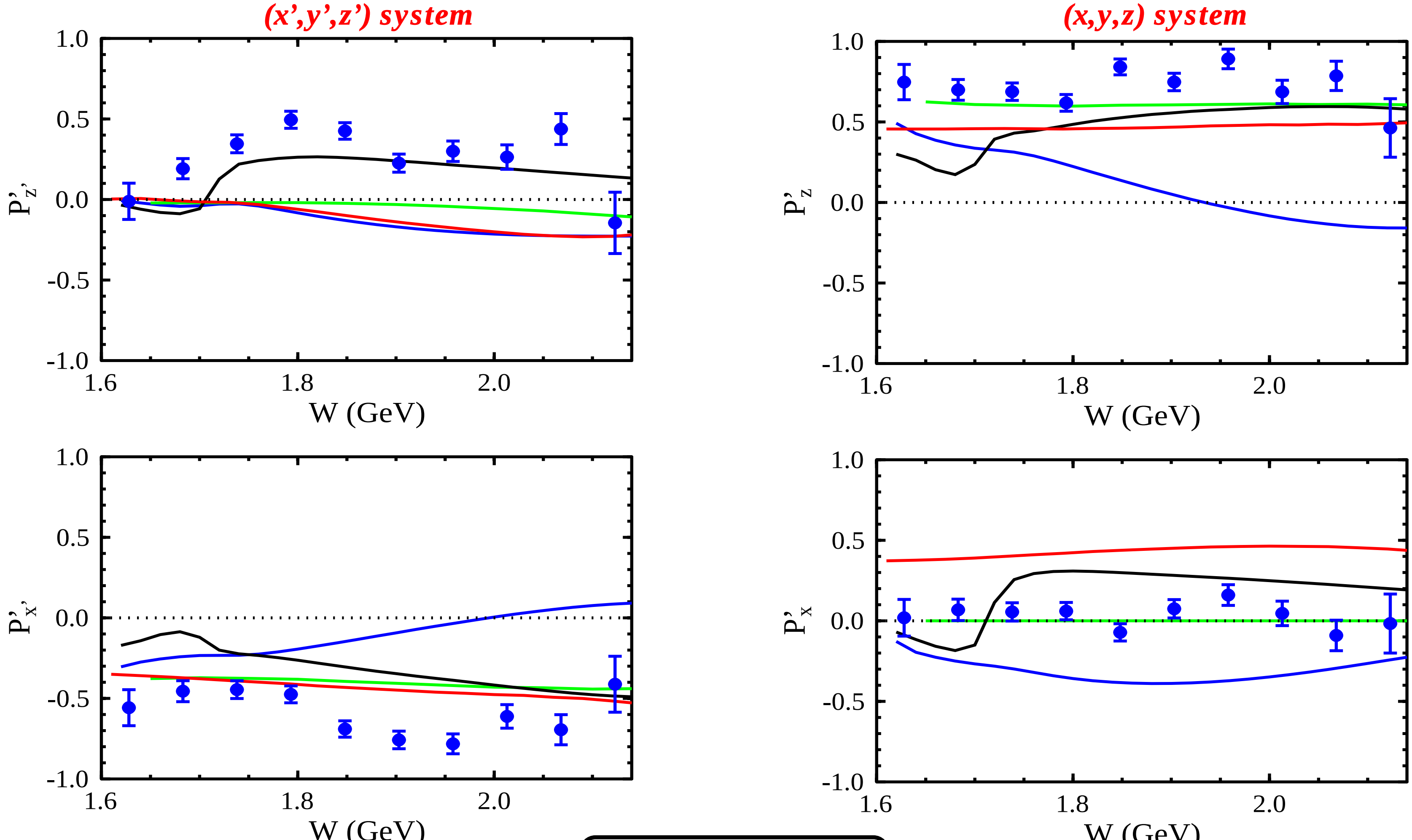
SAPHIR (1998)
SPring−8 (2003)
Hall C (2003)
Harvard−Cornell
Orsay

2.567 GeV
Summed over Q^2, Φ

DSC, PRL 90, 131804 (2003)

Transferred Polarization

$\vec{e} + p \rightarrow e' + K^+ + \vec{\Lambda}$



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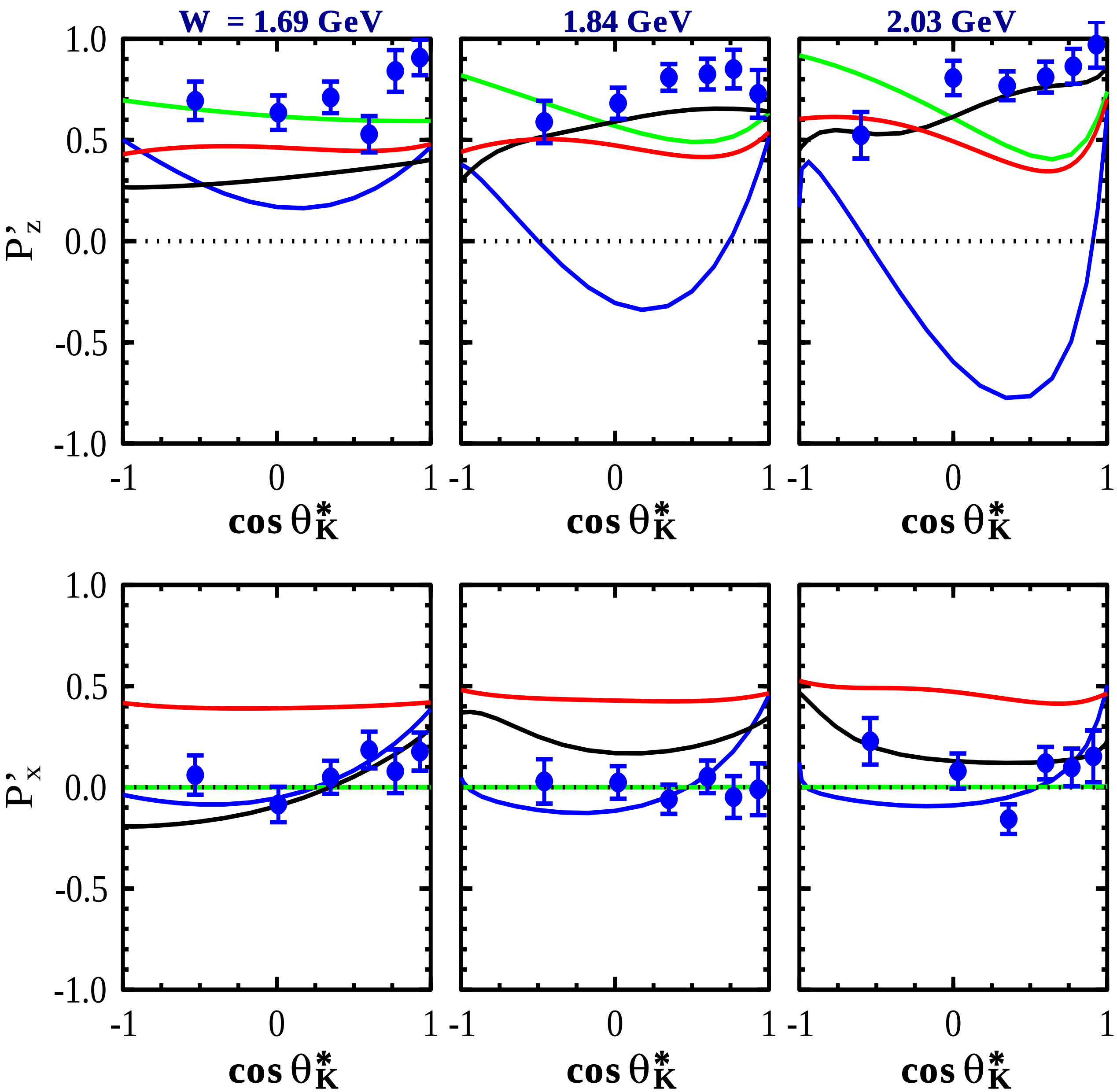
2.567 GeV
Summed over Q^2, $d\Omega_K^*$

DSC, PRL 90, 131804 (2003)

Transferred Polarization

$$\vec{e} + p \rightarrow e' + K^+ + \vec{\Lambda}$$

(x,y,z) system



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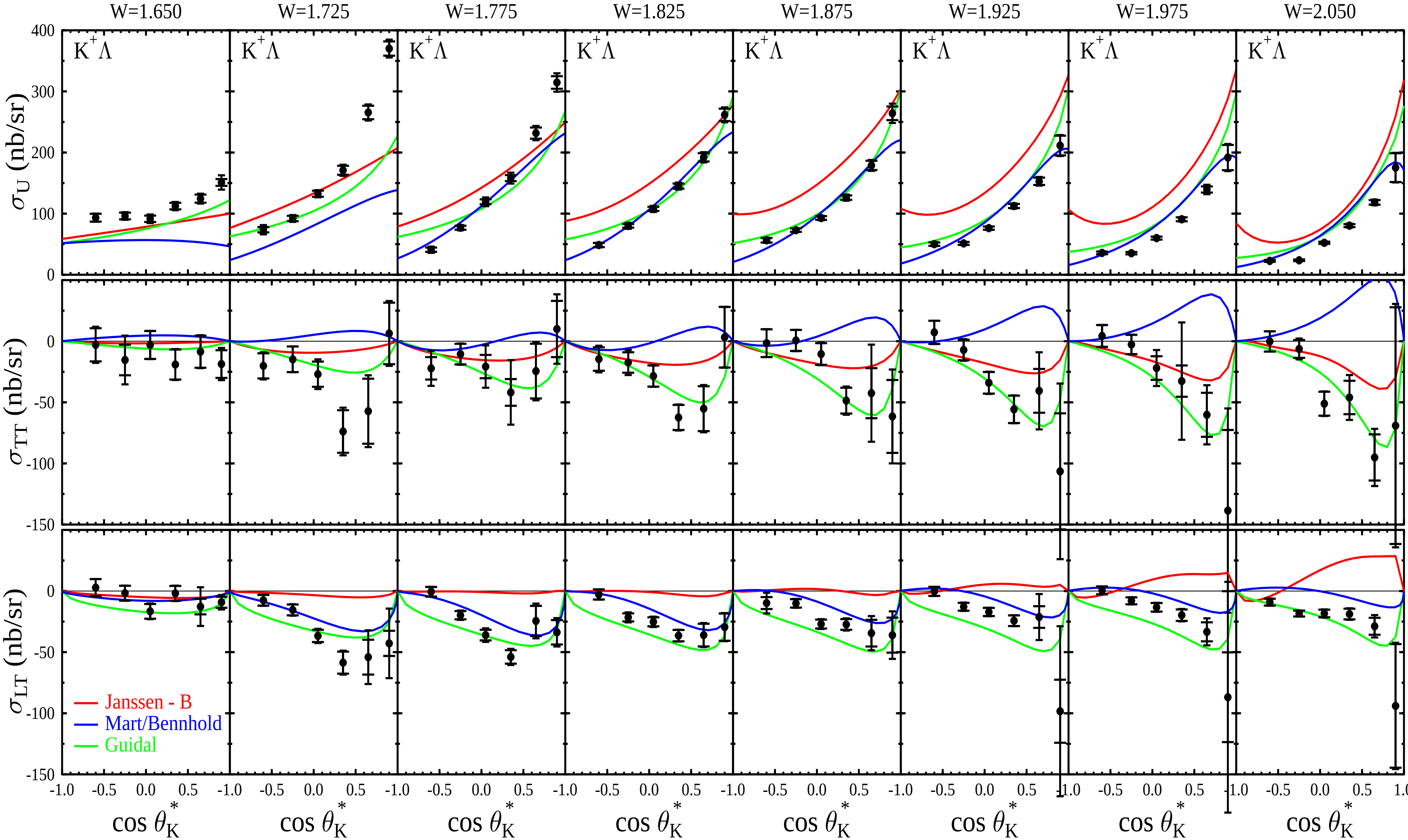

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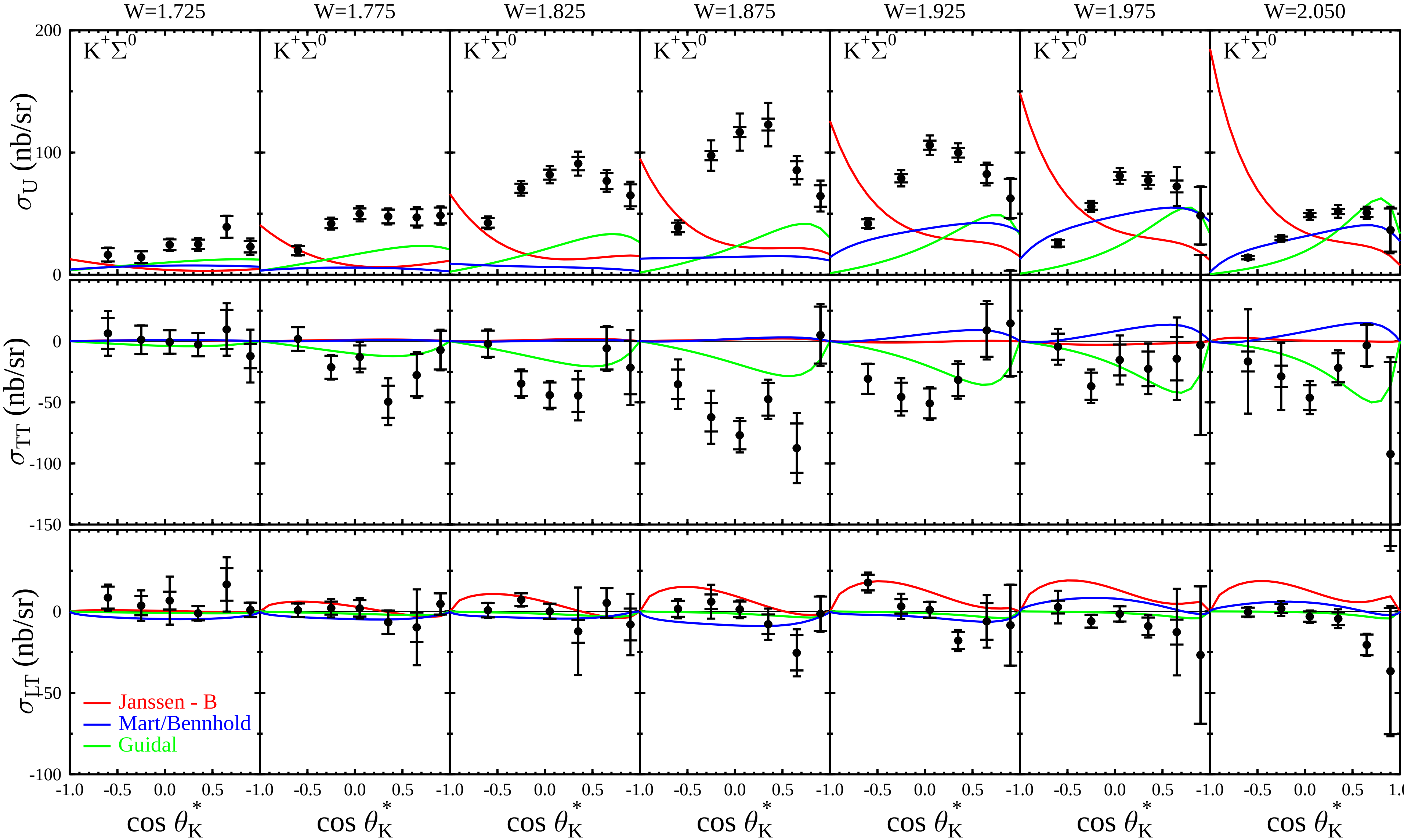

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